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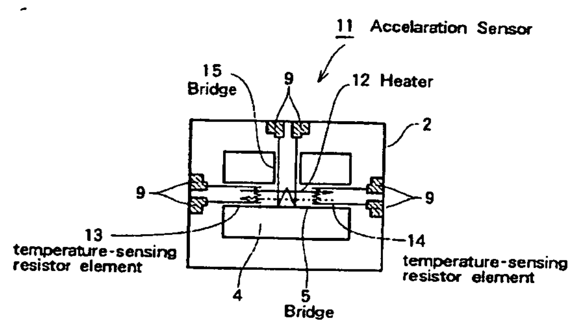
(54) Acceleration sensor.

(57) An acceleration sensor, incorporating a gas-filled closed space in which are disposed resistor elements for heating and/or sensing temperature, is fabricated on a semiconductor or insulating substrate through photoengraving to provide a small, accurate and reliable sensor. Various arrangements of heaters, temperature-sensing resistors and heating and temperature-sensing resistors are described, which detect acceleration direction as well as strength, and are advantageously but not necessarily fabricated using semiconductor technology. In the shown arrangement, heater (12) heats gas in a space (4). An acceleration leftwards causes gas to move to the right, so that resistor (14) heats up and increases its resistance, whilst resistor (13) cools and reduces its resistance. Thus, detection of resistance changes gives acceleration amount and direction. One of the temperature-sensing elements (13,14) may be removed. All three elements (12-14) may be replaced by two elements which both heat the gas and sense temperature.

Fig.4



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The present invention relates to an acceleration sensor for detecting acceleration acting on the sensor body, and, more particularly, to an acceleration sensor for detecting acceleration in the form of changes in the temperature distribution of gas in a closed space.

Disclosed in Published Unexamined Patent Application No. 3-176669 is an acceleration sensor in which the equilibrium of the temperature distribution is formed by heating a gas enclosed in a space closed in a case, and the phenomenon in which the temperature distribution is changed while an air flow is generated by the action of acceleration is detected as a change in the resistance of a resistance temperature sensor disposed within the case.

In the above conventional acceleration sensor, a thin-film-resistor temperature sensor serving also as a heater is disposed in a resin case, and heated by applying current thereto. Resistance values are previously detected for the heated thin-film-resistor temperature sensor at various temperatures.

When acceleration acts on the acceleration sensor, an air flow is generated in the case. The generated air flow takes heat from the thin-film-resistor temperature sensor, thereby reducing its temperature so that the resistance of the thin-film-resistor temperature sensor is changed.

Because the change in the resistance of the thin-film-resistor temperature sensor corresponds to the acceleration acting on the acceleration sensor, the acceleration is detected by converting the resistance of the thin-film-resistor temperature sensor to an electric signal.

The conventional acceleration sensor has, however, a problem that, although it can detect the absolute value of acceleration, it cannot detect the direction in which acceleration acts because it uses the same element to act as both the heater for the gas in the case and the temperature-sensing element which detects the temperature change due to the action of acceleration.

In addition, the conventional acceleration sensor has a problem that, because the thin-film-resistor temperature sensor for the heater serves as both a heater and a temperature-sensing element, aging from deterioration for the temperature is caused in the thin-film-resistor heating-type temperature sensor if the generated temperature is high, leading to variations in heat generation and reduced sensitivity to temperature so that the sensor cannot accurately detect acceleration.

Moreover, the conventional acceleration sensor has a relatively bulky size for the closed space, which results in a degraded response to the temperature change by the air flow. Reduction of the size of the acceleration sensor is limited by its structure.

Furthermore, while the accuracy of acceleration detection depends on the positional accuracy of the thin-film-resistor heating-type temperature sensor, the conventional acceleration sensor has a structure in which the thin-film-resistor heating-type temperature sensor is directly installed on the case, which makes it difficult to accurately position the thin-film-resistor heating-type temperature sensor.

From one aspect, the invention may provide a very small acceleration sensor which is constructed by etching a semiconductor or insulating substrate using a photoengraving process in the semiconductor manufacturing process. Preferably, two sensor cases each with a cavity therein are joined together to form a closed space, with a bridge being formed at the center of one of the sensor cases at the time the cavity is formed, on which is integrally placed a temperature-sensing resistor element and a heater through the photoengraving process, the element accurately detecting imbalance in the temperature distribution generated in the closed space by acceleration acting on the sensor case as a change in resistance of the temperature-sensing resistor element.

From another aspect the invention may provide an acceleration sensor which can accurately detect the absolute value of acceleration acting on the sensor case in any one, two or three-dimensional direction and the direction of action, for example by arranging a pair of temperature-sensing resistor elements in the sensor case in one-dimensional (X axis), two-dimensional (X and Y axes) or three-dimensional (X, Y, and Z axes) axial directions.

As described, because the acceleration sensor is constructed by using the photoengraving process in the semiconductor manufacturing process, resistance values of the temperature-sensing resistor element and the heater and their positioning in the sensor case can be attained with high accuracy.

Therefore, the present invention may provide an acceleration sensor which eliminates problems inherent to the conventional acceleration sensor of poor response to the detection of acceleration due to limitations in the reduction of the size, poor accuracy of acceleration detection due to an inability to accurately position the temperature-sensing resistor element and the heater, time consumed for selecting the resistance for the temperature-sensing resistor element and the heater, and the occurrence of waste parts, and which is very small in size, has excellent accuracy in acceleration detection, and is suitable for mass production.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 is a cross-sectional view of a first embodiment of the acceleration sensor according to the present invention;

FIG. 2 is a plan view of a lower sensor case of the first embodiment of the acceleration sensor according to the present invention;

FIG. 3 is a cross-sectional view of a second embodiment of the acceleration sensor according to the present invention;
FIG. 4 is a plan view of a lower sensor case of the second embodiment of the acceleration sensor according to the present invention;
FIG. 5 is the arrangement of a detection circuit of the acceleration sensor of FIG. 4;
FIG. 6 is a plan view of a lower sensor case of a third embodiment of the acceleration sensor according to the present invention;
FIGS. 7 and 8 are the arrangement of a fourth embodiment of the acceleration sensor according to the present invention;
FIG. 9 is a functional block diagram for the detection of acceleration by using the acceleration sensor of FIGS. 7 and 8;
FIGS. 10 and 11 are the arrangement of a fifth embodiment of the acceleration sensor according to the present invention;
FIG. 12 is a functional block diagram for the detection of acceleration by using the acceleration sensor of FIGS. 10 and 11;
FIG. 13 is another embodiment of the acceleration correction means in FIG. 12;
FIGS. 14 and 15 are the arrangement of a sixth embodiment of the acceleration sensor according to the present invention;
FIG. 16 is a bridge circuit diagram in the acceleration sensor in FIGS. 14 and 15;
FIGS. 17 and 18 are the arrangement of a seventh embodiment of the acceleration sensor according to the present invention;
FIGS. 19 and 20 are the arrangement of an eighth embodiment of the acceleration sensor according to the present invention;
FIG. 21 is the arrangement of essential components of a ninth embodiment of the acceleration sensor according to the present invention;
FIGS. 22a and 22b show perspective and top plan views, respectively, of the appearance of the acceleration sensor shown in Fig.21;
FIG. 23 is a diagram illustrating the operation of the acceleration sensor shown in FIG. 21; and
FIGS. 24 - 27 are diagrams of the acceleration detection circuits of the acceleration sensor shown in FIG. 21.

FIG. 1 is a cross-sectional view of a first embodiment of the acceleration sensor according to the present invention, and FIG. 2 is a plan view of a lower sensor case of the first embodiment of the acceleration sensor according to the present invention. They show the basic arrangement of the acceleration sensor according to the present invention.

Referring to FIGS. 1 and 2, an acceleration sensor 1 comprises a lower sensor case 2 formed therein with a cavity 4 and a bridge 5 by, for example, etching a semiconductor substrate with a fine-processing technique in the semiconductor manufacturing process, and an upper sensor case 3 formed therein with a cavity 7 by etching a semiconductor substrate, a closed space 8 being formed by joining the cases so that the cavities 4 and 7 abut each other.

The closed space 8 is filled with an inert gas with a low heat transfer coefficient such as nitrogen or argon under pressure.

In addition, metal such as platinum-is vapor-deposited on the surface of the bridge 5 of the lower sensor case 2, and etched to form a heat-type temperature-sensing resistor element 6 with a desired pattern.

The bridge 5 is formed to bridge the center of the cavity 4 of the lower sensor case 2. Etching and vapor evaporation are controlled to accurately position the heat-type temperature-sensing resistor element 6 at the center of the closed space 8 when the acceleration sensor 1 is constructed.

An electrode 9 formed by the same material as the heat-type temperature-sensing resistor element 6 is provided on the extension of the heat-type temperature-sensing resistor element 6 to electrically determine changes in the resistance of the heat-type temperature-sensing resistor element 6 which is caused by detecting the supply from an external power supply and the action of acceleration (G).

For the acceleration sensor 1 thus constructed, a thermal equilibrium state with a steep temperature gradient is previously attained by heating the heat-type temperature-sensing resistor element 6 with the supply from the external power supply through the electrode 9.

In the thermal equilibrium state, when acceleration (G) acts on the acceleration sensor 1 in the direction perpendicular to the longitudinal direction of the heat-type temperature-sensing resistor element 6, a gas flow corresponding to the absolute value of the acceleration (G) and its direction of action is generated in the closed space 8, which makes the temperature distribution in the closed space 8 unbalanced and lowers the surface temperature of the he-at-type temperature-sensing resistor element 6.

Lowering of the surface temperature changes the resistance of the heat-type temperature-sensing resistor element 6 so that the absolute value of the acceleration (G) acting on the acceleration sensor 1 can be detected by electrically detecting the change in resistance.

As described above, in the acceleration sensor 1 according to the present invention, the sensor cases 2 and 3, the bridge 5, and the heat-type temperature-sensing resistor element 6 are formed by etching or vacuum evaporation with a fine-processing technique in the semiconductor manufacturing process so that a very small acceleration sensor several millimeters square can be constructed and so that the acceleration can be detected with a quick response and

high accuracy.

Although the first embodiment has the sensor case constructed of a semiconductor substrate, it may also be constructed of an insulating substrate such as glass or ceramic.

In addition, the upper sensor case 3 is not limited to the semiconductor or insulating substrate, but may be constructed of glass or metal.

Furthermore, the sensor may comprise merely the lower sensor case 2 and the heat-type temperature-sensing resistor element 6, without the need necessarily for the upper sensor case 3. In this case, the sensor may then lie, in use, in a space in a body on which the sensor is mounted. For example, if the sensor is to measure the acceleration of a body to which it is attached, the sensor could be mounted on a plate bolted over a small recess in the body such that the sensor lies in the recess. This may be true of later embodiments also.

In the following embodiments, it is also assumed that the sensor case, the bridge, the heater, the temperature-sensing resistor element, and the heat-type temperature-sensing resistor element are formed by using fine-processing technology of the semiconductor manufacturing process.

For example, a photoengraving process for making substrate 2 may comprise the steps of depositing an oxide coating such as SiN on a silicon substrate, depositing platinum or another suitable metal on the SiN, etching the metal to form resistor element patterns, possibly depositing a further oxide coating such as again SiN over the metal patterns, and etching the silicon substrate beneath the oxide coating and metal to make a cavity 4 with a bridge (5) thereabove of the oxide coating with the metal etched patterns thereon. The substrate 3 may also be etched to produce the cavity 7 therein. Both substrates may be placed in an oven and joined with thermosetting resin. The oven may be filled with for example Ar gas, which may be under pressure, for example at over one atmosphere, so that the closed space 2 of the sensor is filled with pressurised Ar gas.

FIG. 3 is a cross-sectional view of a second embodiment of the acceleration sensor according to the present invention, while FIG. 4 is a plan view of a lower sensor case of the second embodiment of the acceleration sensor according to the present invention. They show an embodiment for detecting the absolute value and the direction of acceleration action (G) acting on the acceleration sensor.

Referring to FIGS. 3 and 4, an acceleration sensor 11 comprises a lower case 2 formed therein with a cavity 4 and bridges 5 and 15 by, for example, etching in a semiconductor substrate with a fine-processing technique in the semiconductor manufacturing process, and an upper sensor case 3 formed therein with a cavity 7 by etching a semiconductor substrate, a closed space 8 being formed by joining the cases so that the cavities 4 and 7 abut each other.

Formed on the bridge 5, which extends in the direction in which acceleration (G) is to be measured, are a heater 12 at the center of the bridge 5 in the longitudinal direction, temperature-sensing resistor elements 13,14 opposite each other at a predetermined distance from the center of the bridge 5 in the longitudinal direction, and a lead pattern formed by using vacuum evaporation and etching of a fine-processing technique.

Moreover, the bridge 15 is formed coplanar with and perpendicular to the bridge 5, and has a lead pattern for the heater 12 thereon formed by depositing the same metal as for the heater 12 on its surface, and by etching the metal.

The temperature-sensing resistor elements 13 and 14 are formed in such a manner that a metal pattern is formed by depositing high-melting-point metal such as Pt, Mo, Ni, Au, or Ti, and then etching the metal to form each temperature resistor element with a pattern having a predetermined resistance.

When thermal stability and durability are required for the temperature-sensing resistor elements 13, 14, the surface of the temperature-sensing resistor elements 13, 14 formed by etching is coated by an oxide coating which is formed by an oxide such as SiN.

The pair of temperature-sensing resistor elements 13, 14 and the heater 12 are connected through the lead pattern to respective electrodes 9 provided on the periphery of the lower sensor case 2, electrodes 9 being connected to an external power supply or a detector circuit.

In the acceleration sensor 11 thus constructed, the heater 12 is heated by supplying external power through the electrode 9 to previously create a thermal equilibrium state with a steep temperature gradient in the closed space 8.

In the thermal equilibrium state where no acceleration (G) acts, the temperature-sensing resistor elements 13 and 14 are in the same temperature atmosphere so that each of them exhibits the same resistance value if their resistance and characteristics of temperature coefficient are matched (paired).

When acceleration (G) acts in the equilibrium state in the direction shown in FIG. 4 (indicated by a solid arrow or broken arrow), an air flow is generated in the inert gas, such as nitrogen or argon, enclosed in the closed space 8 to create a thermally unbalanced state in the direction of acceleration action (G) so that the temperature-sensing resistor elements 13 and 14 are subject to different temperatures, respectively.

Since the temperature-sensing resistor elements 13 and 14 generate opposite changes in resistance in the thermally unbalanced state, the absolute value and the direction of acceleration action (G) are detected by electrically detecting the change in resistance.

FIG. 5 shows the arrangement of a detection circuit of the acceleration sensor of FIG. 4.

Referring to FIG. 5, a detector circuit comprises a bridge circuit 16, and reference resistors R1 and R2, and an amplifier 18 which amplifies the differential output of the bridge circuit 16, wherein the bridge circuit 16 constitutes a resistor bridge by connecting the temperature-sensing resistor elements 13 and 14, which is externally provided through the electrodes 9, and reference resistors R1 and R2. A power supply 17 applies power to the bridge circuit 16.

When no acceleration (G) occurs, the bridge circuit 16 maintains the equilibrium state ($R_{X1} \circ R2 = R_{X2} \circ R1$) because the temperature-sensing resistor elements 13 and 14 have the same resistance (R_{X1}, R_{X2}, $R_{X1} = R_{X2}$), and the bridge circuit 16 sets the reference resistors to the same resistance. Then, the bridge output (voltage) becomes zero so that the output V_a of the amplifier 18 also becomes zero.

When acceleration (G) occurs, the temperature-sensing resistor elements 13 and 14 exhibit different resistance values ($R_{X1} > R_{X2}$ or $R_{X1} < R_{X2}$), and the bridge circuit 16 supplies to the amplifier 18 a bridge output (voltage) with negative (-) or positive (+) polarity, depending on the absolute value and the direction of acceleration action (G), and detects the output V_a corresponding to the bridge output from the amplifier 18.

Because the temperature-sensing elements 13 and 14 are formed by a fine-processing technique of the semiconductor manufacturing process, it is possible to accurately provide resistance (R_{X1}, R_{X2}) in a paired state so that the offset of the bridge output (voltage) can be set to a value as close to zero as possible.

The acceleration sensor 11 employs nitrogen gas with a heat transfer coefficient of about 0.024 (kcal/m·h·°C) as the gas enclosed in the closed space 8. When it is assumed that the heater 12 generates heat of about 0.01 (kcal/h) per square millimeter, the temperature gradient (= heat generation/heat transfer coefficient) for the heater 12 can be set to 400 (°C/mm) to make the temperature distribution in the closed space 8 steep so that acceleration in a very small space on a millimeter order can be detected with high sensitivity.

It is possible to further improve the sensitivity of acceleration detection by pressurizing the gas to be enclosed in the closed space 8 to a pressure of more than one atmosphere.

As described, the acceleration sensor 11 can detect acceleration (G) acting on the acceleration sensor with high sensitivity because the closed space 8, the heater 12, and the temperature-sensing resistor elements 13 and 14 can be constructed by using a fine-processing technique of the semiconductor manufacturing process, and their positions can be precisely determined so that a very small acceleration sensor on a millimeter order can be easily obtained.

In addition, the acceleration sensor 11 separately provides the heater 12 and the temperature-sensing resistor elements 13 and 14, which are positioned opposite to the direction to which acceleration (G) occurs, so that the absolute value and the direction of acceleration (G) acting on the acceleration sensor can be detected with high accuracy.

If the acceleration sensor is constructed without using the fine-processing technique of the semiconductor manufacturing process as in the conventional sensor, the ability to reduce its size is limited, and the positioning accuracy of the heater and the temperature-sensing resistor elements in the closed space and the pairing of temperature-sensing resistor elements cannot be fully satisfied, with the result that the sensitivity and accuracy in the detection of acceleration (G) are deteriorated.

FIG. 6 shows a plan view of a lower sensor case of a third embodiment of the acceleration sensor according to the present invention.

Referring to FIG. 6, an acceleration sensor 21 differs from the acceleration sensor 11 of FIG. 4 in that, in place of the temperature-sensing resistor elements 13 and 14, heat-type temperature-sensing resistor elements 19 and 20 are positioned opposite to each other to eliminate the heater 12 and the bridge 15.

Because the heat-type temperature-sensing resistor elements 19 and 20 themselves serve as both heaters and temperature-sensing resistor elements, it is possible to create a thermal equilibrium state in temperature distribution with two heaters, and to detect an unbalanced state in the temperature distribution caused by the action of acceleration (G) with two temperature-sensing resistor elements.

FIGS. 7 and 8 are the arrangement of a fourth embodiment of the acceleration sensor according to the present invention.

Referring to FIGS. 7 and 8, an acceleration sensor 31 comprises an upper sensor case 3 formed therein with a cavity, a lower sensor case 2 having a cavity 4, a heater 32, and a temperature-sensing resistor element 33, the latter two components being provided at bridges of the cavity 4. A gas 34 is enclosed in a closed space formed by the upper and lower cavities.

The heater 32 and the temperature-sensing resistor element 33 are resistors which are formed by depositing and etching platinum or tungsten on a bridge (not shown). The gas 34 is a pressurized gas with a low heat transfer coefficient such as nitrogen gas or argon. The lower sensor case 2 and the upper sensor case 3 are closely attached and joined.

The heater 32 is driven by an external power supply through lead wires 32a and 32b, and generates temperature sufficiently higher than the ambient temperature.

In addition, the temperature-sensing resistor 33

is previously adjusted to have a predetermined resistance value by supplying a small current from the external power supply through lead wires 33a and 33b.

The heat generated from the heater 32 is transferred through the gas 34 to create a temperature distribution corresponding to the distance from the heater 32.

Moreover, use of a pressurized gas with a low heat transfer coefficient such as nitrogen gas or argon creates temperature distribution with a steep temperature gradient corresponding to the distance from the heater 32.

When acceleration (G) acts in the direction indicated by an arrow shown in FIG. 8 (to the left) under a stable temperature distribution in the closed space, the heated gas 34 moves in the direction of P (to the right) to raise the temperature of the temperature-sensing resistor element 33.

As the temperature of the temperature-sensing resistor element 33 is raised, the resistance also rises, if the temperature coefficient is positive, to increase the value of the voltage to be detected on the lead wires 33a and 33b.

On the contrary, if acceleration (G) acts in the opposite direction (to the right), the heated gas 34 moves to the left to reduce the temperature of the temperature-sensing resistor element 33 and also to lower the resistance value of the temperature-sensing resistor element 33 so that the value of the voltage to be detected on the lead wires 33a and 33b is reduced.

The heater 32 and the temperature-sensing resistor element 33 are positioned on a bridge (not shown) at a predetermined distance D.

As described, since the acceleration sensor 31 is constructed by positioning the heater 32 and the temperature-sensing resistor element 33, enclosing the pressurized gas with a low heat transfer coefficient such as nitrogen gas or argon in the closed space to increase the temperature gradient and to detect the temperature with a steep temperature gradient from the heater 32, it can detect the temperature change from the change of acceleration (G) with high accuracy.

FIG. 9 shows a functional block diagram for the detection of acceleration by using the acceleration sensor of FIGS. 7 and 8.

Referring to FIG. 9, the heater 32 is driven by a constant current source (I_H) 35, and generates heat at a high temperature corresponding to the power ($R_H{\ast}I_H^2$) based on the resistance R_H and the current I_H.

In addition, the temperature-sensing resistor element 33 is driven by a constant current source (I_L) 36, set to a resistance value R_C which is the sum of a resistance value at the ordinary temperature and a resistance value corresponding to the temperature transferred from the heater 32, and outputs the voltage at a value V_C ($R_C{\ast}I_L$).

The voltage V_G is an output of the acceleration sensor 31 corresponding to the resistance R_C when no acceleration (G) acts, and input to one terminal (for example, the positive input terminal) of a comparator 37 which is constituted by, for example, an operational amplifier.

The other terminal (for example, a negative input terminal) of the comparator 37 is input with a voltage V_S from a reference resistor R_S. The voltage V_G is set to be equal to the voltage V_S ($V_G = V_S$), for example, when no acceleration (G) occurs.

The comparator 37 calculates and outputs the difference ΔV between the voltage V_G and the voltage V_S (= V_G - V_S). Therefore, the difference ΔV is zero when no acceleration (G) occurs.

When the acceleration (G) occurs in the direction shown in the figure, heat transfer is generated from the heater 32 to the temperature-sensing resistor element 33 so that the resistance R_C of the temperature-sensing resistor element 33 increases, and the difference ΔV exceeds zero ($\Delta V > 0$) to provide a positive voltage.

On the contrary, when the acceleration (G) occurs in the direction opposite to that shown in the figure, the resistance R_C of the temperature-sensing resistor element 33 decreases, and the difference ΔV becomes less than zero ($\Delta V < 0$) to provide a negative voltage.

An acceleration conversion means 38 has a memory such as a ROM which stores, beforehand, a value of the acceleration G_O corresponding to the difference ΔV, and is arranged to output an acceleration signal G_O in response to the input of the difference ΔV.

As described above, the acceleration sensor 31 according to the present invention comprises the heater which heats the gas to create a temperature distribution in the space, and the temperature-sensing resistor element which, when acceleration acts on the sensor case, detects a temperature change from the movement of the gas with the temperature distribution so that it can detect the absolute value and the direction of acceleration action. In addition, because the temperature-sensing resistor element is positioned at a predetermined distance from the heater to detect a temperature lower than that of the heater, the acceleration sensor can maintain stable sensitivity while preventing the deterioration or aging which may be caused by high temperature.

Furthermore, the acceleration sensor 31 according to the present invention employs a pressurized gas with a low heat transfer coefficient as the gas to be enclosed, and can heighten the sensitivity to the temperature detected with the steep temperature gradient so that the acceleration corresponding to the detected temperature can be detected with high accuracy.

FIGS. 10 and 11 are the arrangement of a fifth embodiment of the acceleration sensor according to the present invention.

Referring to FIGS. 10 and 11, an acceleration sensor 41 differs from the acceleration sensor 31 shown in FIGS. 7 and 8 in that a temperature-sensing resistor element for temperature compensation 42 is disposed in a cavity 44 formed in a lower sensor case 2 or outside the lower sensor case 2.

The cavity 44 is formed separately from a cavity 43 to avoid the influence of the heat from the heater 32. Air is enclosed in the closed space so that the temperature-sensing resistor element for temperature compensation 42 detects the ambient temperature.

When the temperature-sensing resistor element for temperature compensation 42 is arranged on a bridge in the cavity 44, it is formed on the same semiconductor substrate as for the heater 32 and the temperature-sensing resistor element 33 by using a fine-processing technique of the semiconductor manufacturing process.

As the temperature-sensing resistor element for temperature compensation 42 and the temperature-sensing resistor element 33 are formed on the same semiconductor substrate with the same semiconductor manufacturing process, the temperature-sensing resistor elements with the same characteristics can be formed so that variations in the characteristics and aging between both temperature-sensing resistor elements can be compensated for.

When the temperature-sensing resistor element for temperature compensation 42 is disposed outside the lower sensor case 2 (the upper sensor case 3 being included), it is attained by attaching, for example, by bonding, to the case the temperature-sensing resistor element for temperature compensation 42 with temperature characteristics matching those of the temperature-sensing resistor element 33.

When left for a sufficient period of time in a predetermined ambient temperature without supplying current to the heater 32, the heater 32, the temperature-sensing resistor element 33, and the temperature-sensing resistor element for temperature compensation 42 are at ambient temperature.

In such state, when current is supplied to the heater 32, the heater 32 generates heat corresponding to the power consumption determined by the supplied current and resistance, and thus is heated. It has a temperature equal to the sum of the temperature from the consumed power and the ambient temperature.

The heat generated from the heater 32 is transferred to the gas 34 such as nitrogen gas or argon to create a temperature distribution with a steep temperature gradient, which is detected by the temperature-sensing resistor element 33. Since the gas 34 and the temperature-sensing resistor element 33 were previously at ambient temperature, the temperature detected by the temperature-sensing resistor 33 is also the sum of the temperature transferred from the heater 32 and the ambient temperature.

For example, if the reference ambient temperature is 20°C, and the ambient temperature is higher than 20°C by a predetermined temperature ΔT, the temperature of the heater 32 is the temperature from the consumed power added to the predetermined temperature ΔT, and the temperature detected by the temperature-sensing resistor element 33 is also the temperature of temperature distribution at the location where the temperature-sensing resistor element 33 is positioned added to the predetermined temperature ΔT.

In addition, because the temperature-sensing resistor element for temperature compensation 42 is also set to the ambient temperature (the reference temperature 20°C plus the predetermined temperature ΔT), it is possible to compensate for the temperature detected by the temperature-sensing resistor element 33 based on the temperature detected by the temperature-sensing resistor element for temperature compensation 42.

Likewise, also, when heat movement is generated by the movement of the gas 34 in the closed space formed by the cavity 43 under the action of acceleration (G), temperature compensation can be attained based on the temperature detected by the temperature-sensing resistor element for temperature compensation 42.

FIG. 12 shows a functional block diagram for the detection of acceleration by using the acceleration sensor of FIGS. 10 and 11.

Referring to FIG. 12, the heater 32 and the temperature-sensing resistor element 33 are driven by a constant-current source (I_H) 35 and a constant-current source (I_L) 36, respectively, and the temperature-sensing resistor element for temperature compensation 42 is driven by a constant-current source (I_L) 45 with the same current as that for the temperature-sensing resistor element 33.

When the heater 32 is not driven ($I_H = 0$), the temperature-sensing resistor element 33 and the temperature-sensing resistor element for temperature compensation 42 detect the ambient temperature. Because the same temperature characteristics are arranged to be provided for both temperature-sensing resistor elements, the resistance R_C is equal to the resistance R_F, and the detection outputs (voltage) V_G and V_R from the temperature-sensing resistor element 33 and the temperature-sensing resistor element for temperature compensation 42 become equal ($V_G = V_R$).

On the contrary, when the heater 32 is driven by the current source (I_H), the rise in temperature from the heater 32 is detected, and the resistance R_C of the temperature-sensing resistor element 33 is increased ($R_C > R_F$) so that the detection output (voltage) V_G is also increased ($V_G > V_R$).

An acceleration correction means 46, comprising a temperature comparator 47, a correction value output means 48, and a correction value memory 49, corrects the detection output V_G from the temperature-sensing resistor element 33 based on the detection output V_R from the temperature-sensing resistor element for temperature compensation 42 to compensate for the variation in the acceleration (G) due to the ambient temperature to allow the actual acceleration G_O acting on the acceleration sensor to be determined.

The temperature comparator 47 consists of a comparator circuit such as a comparator, and stores, beforehand, the detection output V_R provided by the temperature-sensing resistor element for temperature compensation 42. It compares the detection output V_R with a reference voltage V_f corresponding to 20°C, and outputs the difference ΔV_R between the detection output V_R and the reference voltage V_f to the correction value output means 48.

The correction value output means 48 receives the detection output V_G from the temperature-sensing resistor element 33 and the difference ΔV_R, reads an acceleration correction value ΔG corresponding to the detection output V_G and the difference ΔV_R from the correction value memory 49, and provides it to the acceleration conversion means 38.

The correction value output means 48 is set to make the acceleration correction value ΔG to be output as zero when no acceleration (G) acts at an ambient temperature of, for example, 20°C.

The correction value memory 49 consists of a memory such as a ROM and sets, in a table, a correction value ΔG when the difference ΔV_R changes, which correction value is previously determined through experiments for a reference of a difference (V_G - ΔV_R) between the detection output V_R and the difference ΔV_R based on the detection output V_R and the difference ΔV_R.

The acceleration conversion means 38 comprises a memory such as a ROM for converting the detection output V_G to a corresponding acceleration G_O, and a subtractor. The conversion means (38) converts the detection output V_G to acceleration G_O, then calculates the difference (G_O - ΔG) of the correction value ΔG from the acceleration G_O, and outputs the difference as the acceleration G_O.

The acceleration conversion means 38 is set to make the acceleration G_O to be output to zero when no acceleration (G) acts at an ambient temperature of, for example, 20°C.

Thus, as the acceleration G_O to be output is set to zero when no acceleration (G) acts at an ambient temperature of 20°C, and the acceleration correction means 46 compensates for the temperature according to the change in the ambient temperature, it is possible to set the acceleration G_O output from the acceleration conversion means 38 always to zero.

When acceleration (G) acts, as the detection voltage V_G of the temperature-sensing resistor element 33 increases or decreases, the acceleration G_O corresponding to the detection output V_C and corrected for the acceleration with respect to the ambient temperature (correction value ΔG) can be obtained from the acceleration conversion means 38.

The acceleration correction means 46 is an embodiment of an arrangement assuming a case where the ambient temperature changes from the temperature detected at a state where the temperature-sensing resistor element 33 is at the ambient temperature of 20°C and no acceleration (G) occurs, and where the output G_O from the acceleration conversion means 38 corresponding to the detection output V_C is nonlinear.

FIG. 13 shows another embodiment of the acceleration correction means in FIG. 12.

This embodiment represents a case in which the output G_O from an acceleration conversion means 50 and the detection output V_{GO} from an acceleration correction means 46' are linear.

The acceleration correction means 46' comprises a comparator circuit such as a comparator and an arithmetic circuit such as a subtractor, and calculates and outputs a difference V_{GO} (V_G - V_R) between the detection output V_G from the temperature-sensing resistor element 33 and the detection output V_R from the temperature-sensing resistor element for temperature compensation 42.

The acceleration conversion means 50 has a memory such as a ROM for converting the difference output V_{GO} from the acceleration correction means 49 into a corresponding acceleration G_O, converts the difference output V_{GO} into acceleration G_O, and outputs it.

As described above, since the acceleration sensor 41 according to the present invention comprises the temperature-sensing resistor element for temperature compensation for detecting the ambient temperature, and the acceleration correction means for correcting the output signal output from the temperature-sensing resistor element based on the output signal from the temperature-sensing resistor element for temperature compensation, it can detect accurately the acting acceleration by compensating for the influence from the ambient temperature.

FIGS. 14 and 15 are the arrangement of a sixth embodiment of the acceleration sensor according to the present invention.

Referring to FIGS. 14 and 15, an acceleration sensor 51 comprises an upper sensor case 3 formed therein with a cavity, a lower sensor case 2 having a cavity 4, temperature-sensing resistor elements 52 and 53 provided on bridges in the cavity 4, and a pair of reference resistors 54 and 55 externally connected to the temperature-sensing resistor elements 52 and 53 to form a bridge circuit 56, a gas 34 being enclosed

in a closed space formed by the upper and lower sensor cases.

The heat-type temperature-sensing resistor elements 52 and 53 comprise resistors, each of which is formed by depositing and etching platinum or tungsten on a bridge (not shown). The gas 34 employed is a pressurized gas with a low heat transfer coefficient such as nitrogen gas or argon. The lower sensor case 2 and the upper sensor case 3 are closely attached and joined.

In addition, the heat-type temperature-sensing resistor elements 52 (resistor R1) and 53 (resistor R2) are connected by lead wires which are led outside of the sensor case for connecting with the reference resistors 54 (resistor r1) and 55 (resistor r2), which are disposed outside the sensor case, to form a bridge circuit 56. The bridge circuit 56 has terminals (56a - 56d), as shown in FIG. 15, and consists of four resistors.

When power (for example, from a power supply V_I) is applied across the terminals (56a - 56b), the heat-type temperature-sensing resistor elements 52 and 53 generate heat corresponding to the power consumed, and generate, as a heat source with a temperature sufficiently higher than the ambient temperature, a temperature distribution corresponding to the distance from the heat-type temperature-sensing resistor elements 52 and 53 in the closed space.

In this state, the heat-type temperature-sensing resistor elements 52 and 53 have resistances R1 and R2, respectively, so that voltage V_X divided by the resistor R1 and R2 is generated at the terminal (56c).

In contrast, voltage V_Y divided by resistances r1 and r2 of the reference resistors 54 and 55 is generated at the terminal (56d). Thus, resistances R1, R2, r1 and r2 are set in such a manner that the output of the bridge circuit 56 (potential difference V_X - V_Y) is in the equilibrium state (output voltage = 0 V) when no acceleration (G) occurs (R1 = R2, r1 = r2).

In this state, the temperature distribution in the closed space caused by heat generated from the heat-type temperature-sensing resistor elements 52 and 53 is also in the equilibrium state.

In addition, the employment of the pressurized gas with a low heat transfer coefficient, such as nitrogen gas or argon, as the gas 34 results in a temperature distribution corresponding to the distance from the heat-type temperature-sensing resistor elements 52 and 53 in the closed space with a steep temperature gradient.

When acceleration (G) acts in the direction indicated by the arrow shown in FIG. 15 in the equilibrium state, the gas 34 moves in the direction of P to cause heat movement from the heat-type temperature-sensing resistor element 52 to the heat-type temperature-sensing resistor element 53.

When the heat movement (direction of P) occurs, the thermal equilibrium in the closed space is destroyed, the temperature of the heat-type temperature-sensing resistor element 52 decreases, and the temperature of the heat-type temperature-sensing resistor element 53 increases so that the resistance R1 of the heat-type temperature-sensing resistor element 52 decreases and the resistance R2 of the heat-type temperature-sensing resistor element 53 increases.

When, with the occurrence of acceleration (G), the resistance R2 increases and the resistance R1 decreases, the output of the bridge circuit 56 also becomes unbalanced so that the potential difference V_X - V_Y detects a positive value ($V_X - V_Y > 0$) corresponding to the acceleration (G).

In contrast, when acceleration (G) acts in the direction opposite to the arrow shown in FIG. 15, a reverse phenomenon occurs, that is, the resistance R1 increases and the resistance R2 decreases so that the output of the bridge circuit 56 detects a negative potential value ($V_X - V_Y < 0$) corresponding to the acceleration (G).

Thus, the acceleration sensor 51 detects the magnitude of the acting acceleration (G) with the absolute value of the output of the bridge circuit 56 (potential difference V_X - V_Y), and the acting direction of acceleration (G) with the sign of the output (positive or negative of potential difference V_X - V_Y).

The output of the bridge circuit 56 (potential difference V_X - V_Y) will be explained in the following:

FIG. 16 shows a bridge circuit diagram in the acceleration sensor of FIGS. 14 and 15.

Referring to FIG. 16, the bridge circuit 56 consists of the resistances R1 and R2 of the heat-type temperature-sensing resistor elements 52 and 53, and the resistances r1 and r2 of the reference resistors 54 and 55, a power supply (for example, the voltage source V_I) being connected between the terminals (56a - 56b), the output occurring across the terminals (56c - 56d).

The voltage V_X at the terminal (56c) and the voltage V_Y at the terminal (56d) with respect to ground (GND) is calculated by using equation 1, as follows:

$$V_X = R2 \cdot V_I/(R1 + R2), \text{ and}$$
$$V_Y = r2 \cdot V_I/(r1 + r2) \quad (1)$$

Based on equation 1, the output potential difference of the bridge circuit 56 V_O (= V_X - V_Y) can be represented by the following, equation 2:

$$V_O = V_X - V_Y$$
$$= (R2 \cdot r1 - R1 \cdot r2) V_I/\{(R1 + R2) \cdot (r1 + r2)\} \quad (2)$$

In equation 2, by setting R1 = R2 and r1 = r2, the output potential difference $V_O = 0$ can be obtained in the equilibrium state where no acceleration (G) occurs.

When, in the equilibrium state, the acceleration (G) shown in FIG. 15 occurs, and the heat movement (direction of P) causes a decrease in the resistance R1 by ΔR and an increase in the resistance R2 by ΔR,

the output potential difference V_O (= V_X - V_Y) becomes the value represented by equation 3:

$$V_O = V_X - V_Y$$
$$= \Delta R * (r1 + r2) V_I/\{(R1 + R2) * (r1 + r2)\}$$
$$= \Delta R * V_I/2R \quad (3)$$

where, R1 = R2 = R, r1 = r2 = r.

Thus, the output potential difference V_O can provide a value proportional to the variation ΔR of resistance corresponding to acceleration (G).

However, when acceleration (G) acts in a direction opposite to that shown in FIG. 15, the output potential difference V_O provides a value with the opposite-sign to equation 3 ($-\Delta R * V_I/2R$).

As described above, because, in the acceleration sensor 51 according to the present invention, a pair of heat-type temperature-sensing resistor elements is disposed with a predetermined distance in a closed space containing a pressurized gas with a low heat transfer coefficient, and a bridge circuit is constituted by a pair of heat-type temperature-sensing resister elements and a pair of external reference resistors, it is possible to detect heat movement in the case, which is caused by the action of acceleration, with the change in resistance of the pair of heat-type temperature-sensing resistor elements, to detect the absolute value of acceleration at a high accuracy with the output voltage of the bridge circuit and its sign, and to detect the direction in which acceleration is acting.

FIGS. 17 and 18 are the arrangement of a seventh embodiment of the acceleration sensor according to the present invention.

Referring to FIGS. 17 and 18, the acceleration sensor 61 differs from the acceleration sensor 51 shown in FIG. 14 in that heat-type temperature-sensing resistor elements 62 and 63 are disposed at a predetermined distance D in a closed space in a lower sensor case 2, and a plurality of heaters 64 (R_{11} - R_{1n}, R_{21} - R_{2n}, R_{31} - R_{3n}) are positioned on both sides of the heat-type temperature-sensing resistor elements 62 and 63.

Furthermore, similar to FIG. 15, the heat-type temperature-sensing resistor elements 62 and 63, and the reference resistors 54 and 55 constitute the bridge circuit 56 shown in FIG. 15.

The heaters 64 (R_{11} - R_{1n}, R_{21} - R_{2n}, R_{31} - R_{3n}) are heated by, for example, connecting the elements in series and connecting a power supply across the terminals (56e - 56f).

In addition, a voltage source V_I is connected across the terminals (56a - 56b) of the bridge circuit 56 to heat the heat-type temperature-sensing resistor elements 62 and 63.

It is assumed that the heat-type temperature-sensing resistor elements 62 and 63 have resistances R1 and R2 when the temperature distribution in the closed space caused by the heat generation of the heat-type temperature-sensing resistor elements 62 and 63, and the heaters 64 (R_{11} - R_{1n}, R_{21} - R_{2n}, R_{31} - R_{3n}) reaches equilibrium. Then, the bridge circuit 56, constituted by resistances r1 and r2 of the standard resistors 54 and 55 and resistances R1 and R2, is set in that state in which its output (output potential difference V_O) is in an equilibrium state ($V_X - V_Y = 0$).

When heat movement is generated in the closed space in the direction of the arrow (direction of P) by the action of acceleration (G) in the direction shown in FIG. 18, heat moves from the heat-type temperature-sensing resistor element 62 to the heat-type temperature-sensing resistor element 63 as described for FIG. 15 to decrease the resistance R1 and to increase the resistance R2.

Since the decrease in the resistance R1 and the increase in the resistance R2 provide a value larger than the variation in FIG. 15 (for example, $k*\Delta R$) because of the heat movement in the heaters 64 (R_{11} - R_{1n}, R_{21} - R_{2n}, R_{31} - R_{3n}), the bridge output V_O ($V_X - V_Y$) becomes $k*\Delta R*V_I/2R$ times the relationships of equations 1 - 3.

Thus, because the acceleration sensor 61 is provided with a plurality of heaters 64, the movement of heat (temperature change) can be set at a linear value, and provide larger bridge output than that of the arrangement of FIG. 14 can be obtained for the same acceleration (G) so that the detection accuracy can be improved.

In contrast, when the direction of acceleration (G) is reversed, the bridge output V_O of $-k*\Delta R*V_I/2R$ is obtained.

It is the same as in the arrangement of FIG. 14 to employ a pressurized gas with a low heat transfer coefficient such as nitrogen gas or argon as the gas 34 used.

As described, since the acceleration sensor 61 according to the present invention provides a plurality of heaters together with a pair of heat-type temperature-sensing resistor elements in the closed space, the heat movement (temperature change) in the closed space can be increased so that the absolute value of acceleration can be detected with a high accuracy.

FIGS. 19 and 20 are the arrangement of a eighth embodiment of acceleration sensor according to the present invention.

Referring to FIGS. 19 and 20, an acceleration sensor 71 differs from the arrangements shown in FIGS. 14 and 15 in that heat-type temperature-sensing resistor elements 74 and 75 corresponding to the standard resistor (r1) 54 and the standard resistor (r2) 55 shown in FIG. 15 are provided in the closed space in the lower sensor case 2 together with the heat-type temperature-sensing resistor elements 72 and 73, and in that a bridge circuit 56 is constituted by the heat-type temperature-sensing resistor elements 72, 73, 74 and 75.

A power supply V_I is connected across the terminals (56a - 56b) to heat the heat-type temperature-

sensing resistor elements 72, 73, 74, and 75. The resistance R1, R2, r2, and r1 are set to values to make equilibrium ($V_X - V_Y = 0$) the output V_O (across the terminals 56c - 56b) of the thermally balanced bridge circuit 56 in the closed space.

When the movement of heat in the direction of P is generated in the closed space as acceleration (G) acts in the direction of the arrow, heat moves from the heat-type temperature-sensing resistor elements 72 and 74 to the heat-type temperature-sensing resistor elements 73 and 75 to decrease the resistances R1 and r2 and to increase the resistances R2 and r1.

When it is assumed that the decrease in the resistances R1 and r2 is $-\Delta R$ and $-\Delta r$, and the increase in the resistances R2 and r1 is ΔR and Δr, the bridge output V_O ($V_X - V_Y$) is represented by equation 4:

$$V_O = V_X - V_Y$$
$$= (R \circ \Delta r + r \circ \Delta R)\, V_I/(2R \circ r) \quad (4)$$

where R1 = R2 = R, and r1 = r2 = r

Thus, the acceleration sensor 71 provided with the heat-type temperature-sensing resistor elements 74 and 75 can set the movement of heat (temperature change) to a large value, and a larger bridge output can be obtained for the same acceleration (G) than for the arrangements of FIGS. 14 and 15 so that the detection accuracy of the sensor can be made higher.

It is the same as in the arrangement of FIG. 14 to employ a pressurized gas with a low heat transfer coefficient such as nitrogen gas or argon as the gas 34 used, and to position the heat-type temperature-sensing resistor elements 72 and 73 at a relative distance D.

As described above, since, in the acceleration sensor 71 according to the present invention, two pairs of heat-type temperature-sensing resistor elements are provided in the closed space, and the bridge circuit is constituted by four heat-type temperature-sensing resistor elements, the absolute value of acceleration can be detected at a higher accuracy.

FIG. 21 is the arrangement of essential components of a ninth embodiment of an acceleration sensor according to the present invention.

Referring to FIG. 21, an acceleration sensor 81 is an embodiment of a three-axis acceleration sensor, and constituted by four types of semiconductor substrates 82 - 85.

The semiconductor substrates 82 - 85 are formed therein with a cavity, a space, heaters, and temperature-sensing resistor elements by a fine-processing technique in the semiconductor manufacturing process such as etching or depositing.

Dimensions and placement of the space, the heaters, the temperature-sensing elements, and external connection pads can be very finely determined by a mask so that they can be attained with a high accuracy.

The semiconductor substrate 82 constitutes the cover for a sensor case for the acceleration sensor 81 in which a cavity 86 is very finely processed and formed by etching.

The semiconductor substrate 83 is formed with a temperature-sensing resistor element Z1 upward in the direction of the Z axis, external connection pads (91a) and (92b) for connecting the temperature-sensing resistor element Z1 to the outside, and a space 87 extending through the Z axis.

The temperature-sensing resistor element Z1 is formed by etching based on a fine pattern diagram which represents a mask for manufacturing conductors to be formed on a bridge (not shown), which is formed on the top of the semiconductor substrate by, for example, etching, by depositing or crystal growing metal such as platinum or tungsten.

The temperature-sensing resistor element Z1 is formed on the diagonal line, or in the X direction, or in the Y direction, so that it is positioned at the center of the top of the substrate.

The external connection pads (91a) and (91b), and a lead pattern for electrically connecting the temperature-sensing resistor element Z1 and the external connection pads (91a) and (91b) are also formed by depositing or crystal growing metal such as platinum or tungsten as in the temperature-sensing resistor element Z1.

The semiconductor substrate 83 is formed of a sufficiently large size so that the external connection pads (91a) and (91b) appear on the surface of the substrate when it is stuck together with the semiconductor substrate 82, and the upper surface of the space 87 aligns the plane of the cavity 86 in the semiconductor substrate 82.

The semiconductor substrate 84 includes a heater H, pairs of temperature-sensing resistor elements X1 and X2, and Y1 and Y2 facing the heater H and respectively disposed in the directions of the X and Y axes, external connection pads (93a, 93b, 94a, 94b, 95a, 95b, 96a, 96b, 97a, and 97b) for connecting the heater H, and the temperature-sensing resistor elements X1, X2, Y1, and Y2 to the outside, and a space 88 extending through the Z axis.

The heater H is formed so as to be positioned at the center of the space 88 on the top of the semiconductor substrate 84.

The heater H, and the pairs of temperature-sensing resistor elements X1 and X2, and Y1 and Y2 are formed by depositing and etching metal such as platinum and tungsten on a bridge (not shown) which is formed by etching as in the temperature-sensing resistor element Z1 on the semiconductor substrate 83.

The heater H and the temperature-sensing resistor elements X1, X2, Y1, and Y2 differ in that the resistance of the heater H is lower than the temperature-sensing resistor elements X1, X2, Y1, and Y2.

A lead pattern is also formed by deposition or the like and etching metal such as platinum or tungsten for electrically connecting the heater H and the tem-

perature-sensing resistor elements X1, X2, Y1, and Y2 to the external connection pads (93a, 93b, 94a, 94b, 95a, 95b, 96a, 96b, 97a, and 97b).

The space 88 is formed in the same size as the space 87 to pass through the Z axis.

The semiconductor substrate 84 is formed of a sufficiently large size so that the external connection pads (93a, 93b, 94a, 94b, 95a, 95b, 96a, 96b, 97a, and 97b) appear on the surface of the substrate when it is stuck together with the semiconductor substrate 83, and the upper surface of the space 88 aligns the plane of the space 87 in the semiconductor substrate 83.

The semiconductor substrate 85 is formed with a temperature-sensing resistor element Z2 downward in the direction fo the Z axis, external connection pads (92a) and (92b) for connecting the temperature-sensing element Z2 to the outside, and a space 89 which forms the bottom of the sensor 81 case downward in the direction of the Z axis.

The temperature-sensing resistor element Z2 is arranged to be paired with the temperature-sensing resistor element Z1 on the semiconductor substrate 83 with respect to the heater H on the semiconductor substrate 84.

The temperature-sensing resistor element Z2 is formed in a manner similar to that for the temperature-sensing resistor element Z1 on the semiconductor substrate 83. The semiconductor substrate 85 is formed of a sufficiently large size so that the external connection pads (92a) and (92b) appear on the surface of the substrate when it is stuck together with the semiconductor substrate 84, and the upper surface of the space 89 aligns the plane of the space 88 in the semiconductor substrate 84.

After the semiconductor substrates 82 - 85 are completely arranged, the semiconductor substrates 83, 84 and 85 are stacked and joined in the direction of the Z axis direction so as to align the spaces 87 - 89, and a pressurized gas with a low heat transfer coefficient such as nitrogen or argon is introduced into the space while joining the semiconductor substrate 82 to form a pyramid acceleration sensor 81.

Positioning recesses may be provided in the upper surfaces of the semiconductor substrates 83 - 85 in joining the semiconductor substrates 82 - 85.

Although the embodiment is described for a three-axis (X, Y, and Z axes) acceleration sensor, a two-axis (X and Y axes) acceleration sensor can be constituted by eliminating the semiconductor substrates 83 and 85, and providing a bottom on the space 88 in the semiconductor substrate 84 similar to the space 89 in the semiconductor substrate 85.

The thus-constituted acceleration sensor 81 can attain accurate positioning of the heater H and the temperature-sensing resistor elements X1, X2, Y1, Y2, Z1, and Z2 by using a fine-processing technique in the semiconductor manufacturing process so that alignment can be accurately achieved,

Also, since the temperature-sensing resistor elements X1, X2, Y1, Y2, Z1, and Z2 are formed on the same semiconductor substrate or the semiconductor substrates of the same production lot, the acceleration sensor 81 can be obtained with good pairing (resistivity and temperature coefficient) of X1 and X2, Y1 and Y2, and Z1 and Z2.

Furthermore, because the acceleration sensor 81 is formed by the fine-processing technique in the semiconductor manufacturing process, it can be produced in the minimum size necessary for a sensor so that miniaturization can be attained.

FIGS. 22a and 22b show in perspective and top plan view the appearance of the acceleration sensor shown in FIG. 21.

Referring to FIGS. 22a and 22b, the acceleration sensor 81 has the semiconductor substrates 82 - 85 described for FIG. 21, and is constituted in a pyramid acceleration sensor by stacking and joining the semiconductor substrates 82 - 85 in the direction of the Z axis.

Disposed in the closed space 90 are the heater H, and the temperature-sensing resistor elements X1, X2, Y1, Y2, Z1, and Z2 for detecting acceleration in the three axes (X, Y, and Z axes). The pressurized gas 91 with a low heat transfer coefficient such as nitrogen or argon is also enclosed in the space 90.

In addition, disposed on the surface of the acceleration sensor 81 are the external connection pads of the heater H (bonding pads 91a - 97b) and of the temperature-sensing resistor elements X1, X2, Y1, Y2, Z1, and Z2 for connection with an external acceleration detector circuit (not shown).

Detection of acceleration by the acceleration sensor 81 according to the present invention will be explained in the following section:

FIG. 23 is a diagram illustrating the operation of the acceleration sensor shown in FIG. 21.

Referring to FIG. 23, in the closed space 90 of the acceleration sensor 81 shown in FIGS. 21 and 22, the heater H is disposed at the center of the X-Y plane at the center of the Z axis, and a pair of temperature-sensing resistor elements X1 (resistance R1) and X2 (resistance R2); and a pair of temperature-sensing resistor elements Y1 (resistance R3) and Y2 (resistance R4) are disposed opposite to each other with respect to the X and Y axes, respectively, in symmetry with the heater H (resistance R).

In addition, a pair of temperature-sensing resistor elements Z1 (resistance R5) and Z2 (resistance R6) is disposed opposite to each other with respect to the Z axis in symmetry with the heater H (resistance R).

Furthermore, enclosed in the closed space 90 is a pressurized gas 91 with a low heat transfer coefficient such as nitrogen or argon. The heater H generates Joule heating corresponding to the electrical power (V_O^2/R or $I_O^2 * R$) by driving it with an external

power supply (for example, a voltage source V_O or a current source I_O).

The gas 91 is heated by Joule heating, and a temperature distribution inversely proportional to the distance from the heater H is created in the closed space 90 with a steep temperature gradient.

Because the temperature-sensing resistor elements X1, X2, Y1, Y2, Z1, and Z2 are positioned at equal distances from the heater H in the X, Y, and Z axes, respectively, when no acceleration (G) acts on the acceleration sensor 81, the temperature-sensing resistor elements are in an equal temperature environment and thermally balanced, and the resistance R1 - R6 are in the relationships of R1 = R2, R3 = R4, and R5 = R6.

When acceleration (G) occurs, for example, in the direction of the X (-X) axis as in FIG. 23 in the thermally balanced state, the temperature distribution in the closed space 90 moves in the direction opposite to the direction of acceleration (G), the temperature balance between the temperature-sensing resistor elements X1 and X2 is destroyed to increase the temperature of the temperature-sensing resistor element X1, and to decrease that of the temperature-sensing resistor element X2.

Because the increase in the temperature of the temperature-sensing resistor element X1 increases the resistance R1, while a decrease in the temperature of the temperature-sensing resistor element X2 decreases the resistance R2, when an arrangement is made to detect acceleration (G) with a value corresponding to the resistance difference (R1 - R2) between the resistances R1 and R2, the resistance difference (R1 - R2) becomes a positive value (R1 - R2 > 0) so that the magnitude of acceleration (G) can be detected from the value corresponding to the resistance difference, and the direction of acceleration (G) can be detected from the sign (+ or -) of the resistance difference.

In contrast, when acceleration (G) acts in a direction opposite to that in FIG. 23, the resistance difference (R1 - R2) takes a negative value (R1 - R2 < 0) so that the magnitude and the direction of acceleration (G) can be detected from a value corresponding to the resistance difference and its sign (+ or -), respectively.

When acceleration (G) acts in the direction of the X axis, the temperature-sensing resistor elements Y1 and Y2, as well as Z1 and Z2 in the directions of the Y and Z axes are thermally balanced, therefore both the resistance difference (R3 - R4) and (R5 - R6) becomes zero, and the temperature-sensing resistor elements are not affected by acceleration (G).

Similarly, when acceleration (G) acts in the direction of the Y or Z axis, the thermal balance is destroyed in the temperature-sensing resistor elements Y1 and Y2 or Z1 and Z2 positioned in the direction of acceleration (G) so that the acceleration (G) can be detected from a value corresponding to the resistance difference (R3 - R4) or (R5 - R6) and their sign (+ or -).

FIGS. 24 - 27 are diagrams of acceleration detector circuits of the acceleration sensor shown in FIG. 21.

FIG. 24 shows a diagram of the heater driving circuit, FIG. 25 a diagram of the acceleration detector circuit in the direction of the X axis, FIG. 26 a diagram of the acceleration detector circuit in the direction of the Y axis, and FIG. 27 a diagram of the acceleration detector circuit in the direction of the Z axis.

Although FIGS. 24-27 show examples in which the driving power supply is constituted by a current source (I_O), they may be constituted by a voltage source (V_O).

The heater driving circuit shown in FIG. 24 supplies current to the resistance R of the Heater H from a current source (I_O) to generate Joule heating corresponding to the electrical power ($I_O^2 \cdot R$).

The acceleration detector circuit in the direction of the X axis shown in FIG. 25 constitutes a resistor bridge circuit with the temperature-sensing resistor elements X1 (resistance R1) and X2 (resistance R2), and standard resistors Ro1 and Ro2, and is arranged to output difference V_{OX} (V_{X1} - V_{X2}) based on the bridge output voltage V_{X1} and V_{X2} through a differential amplifier A_X, and to obtain a detection output corresponding to acceleration (G) acting in the direction of the X axis.

FIGS. 26 and 27 similarly constitute a resistor bridge circuit, and are arranged to output difference V_{OY} (V_{Y1} - V_{Y2}) and V_{OZ} (V_{Z1} - V_{Z2}) based on the bridge output voltage V_{Y1} and V_{Y2}, as well as V_{Z1} and V_{Z2}, and to obtain a detection output corresponding to acceleration (G) acting in the direction of the Y or Z axis direction.

As described, because the absolute values and the directions of acceleration (G) acting in the X, Y and Z axis directions can be detected from the difference (V_{OX}, V_{OY} and V_{OZ}) and their sign (+ or -), it is possible to detect acceleration (G) acting in any of three dimensional directions by providing a calculation means for calculating the mean square $\sqrt{(V_{OX}^2 + V_{OY}^2 + V_{OZ}^2)}$ and an orientation determination means for determining the quadrant of a three-dimensional XYZ coordinate system from the sign (+ or -) of each difference.

As described above, since the acceleration sensor 81 according to the present invention is arranged by forming the sensor case forming the closed space, the heaters, a pair of temperature-sensing resistor elements disposed in each of multiple axis directions on a plurality of separate semiconductor substrates with the semiconductor manufacturing process, and by joining the plurality of semiconductor substrates in one direction, it is possible to easily align the plurality of temperature-sensing resistor elements with the

multiple axes which are orthogonal to each other, and to form the temperature-sensing resistor elements with matched characteristics so that a very small acceleration sensor can be attained with less variation and higher accuracy.

Furthermore, since the acceleration sensor 81 according to the present invention employs pressurized gas with a low heat transfer coefficient as the gas to be enclosed in the closed space, it is possible to create a steep temperature gradient and to attain a sensor with high sensitivity.

As described above in detail for various embodiments, because the present invention very finely processes the semiconductor substrates and the like with a fine-processing technique in the semiconductor manufacturing process, accurately forms the sensor case, the heater, the temperature-sensing resistor element, the heat-type temperature-sensing resistor element and the like, and accurately determines their relative placement, the present invention can provide a miniaturized and economic acceleration sensor which can detect acceleration acting on the sensor with a high accuracy.

Furthermore, because the present invention encloses a pressurized inert gas with a low heat transfer coefficient in the closed space formed by the sensor case, the present invention can provide an acceleration sensor which can detect acceleration acting on the sensor with a high sensitivity by increasing the temperature gradient in the closed space.

Furthermore, because the present invention disposes a pair of temperature-sensing resistor elements with good pairing (resistivity, and temperature coefficient) in the direction of acceleration, it can provide an acceleration sensor which can detect the absolute value and the direction of acceleration more accurately.

Furthermore, because the present invention disposes a pair of temperature-sensing resistor elements with good pairing (resistivity, and temperature coefficient) in each of the three-dimensional axis directions, it can provide an acceleration sensor which can accurately detect acceleration acting in any of the three-dimensional directions.

Although the embodiments describe sensors fabricated by photoengraving semiconductor or insulating substrates, the invention encompasses sensors which comprise a heater and one or more separate temperature-sensing resistor elements, as well as sensors which comprise two or more heat-type temperature-sensing resistor elements, no matter how they are fabricated. Such sensors still provide advantages, such as the ability to detect acceleration direction, even though they may not be as sensitive or as small as, for example, semiconductor sensors.

The invention is not limited to the disclosed embodiments, which are given by way of example only, and various modifications can be envisaged, including combinations of the features of the embodiments described.

Claims

1. An acceleration sensor comprising a temperature-sensing resistor means disposed, in use, within a closed space, gas in the space being heated, and wherein the resistance of the resistor means changes when an acceleration acts on the sensor due to flow of the gas over the resistor means, characterised in that the sensor comprises a semiconductor or insulating substrate having a cavity therein, with the resistor means extends at least part way across the cavity, and in that the cavity and resistor means are fabricated using a photoengraving process.

2. The sensor of claim 1, wherein a second substrate is mounted on the cavitied substrate to close the cavity and form the closed space.

3. The sensor of claim 1 or 2, wherein the resistor means is integrally formed on a projection of the semiconductor or insulating substrate extending into the closed space.

4. The sensor of claim 3, wherein the resistor means is formed by the deposition of a metal onto the projection and by etching of the metal to form a desired resistive pattern.

5. The sensor of any preceding claim, wherein the resistor means is a heat-type temperature sensing resistor element which is used to both heat the gas and indicate acceleration by changing resistance.

6. An acceleration sensor comprising a temperature-sensing resistor means disposed, in use, within a closed space, gas in the space being heated, and wherein the resistance of the resistor means changes when an acceleration acts on the sensor due to flow of the gas over the resistor means, characterised in that the sensor comprises heater means for heating the gas, and in that the resistor means is spaced from the heater means.

7. The sensor of claim 6, wherein the sensor comprises a further temperature-sensing resistor means disposed on the opposite side of the heater means to the first resistor means.

8. An acceleration sensor comprising a heat-type temperature-sensing resistor means disposed, in use, within a closed space, the resistor means

heating the gas and indicating acceleration of the sensor through a change in its resistance caused by gas flow thereacross, characterised in that the sensor comprises a further heat-type temperature-sensing resistor means, spaced from the first heat-type temperature-sensing resistor means, which also heats the gas and indicates acceleration through a change in resistance.

9. The sensor of claim 6, 7 or 8, wherein besides the heater means and temperature-sensing resistor means, or the pair of heat-type temperature-sensing resistor means, the sensor includes further such means in order to sense accelerations in two or three orthogonal directions.

10. The sensor of any of claims 6-9, wherein the sensor comprises a semiconductor or insulating substrate having a cavity therein for defining a portion of said closed space, the cavity and resistor means being fabricated using a photoengraving process.

11. The sensor of any preceding claim, including a bridge circuit for detecting the change in resistance of one or more of the resistor means.

12. The sensor of claim 11, wherein reference resistors of the bridge circuit comprise further temperature-sensing resistor means disposed in the closed space.

13. The sensor of any of claims 1 to 10, including comparator means to compare the output of a resistor means with a reference, in order to determine a change in resistance.

14. The sensor of any preceding claim, comprising a further temperature-sensing resistor means for detecting ambient temperature, with means being provided to correct the sensor output in accordance with the detected ambient temperature.

15. The sensor of any preceding claims, wherein one or more further heaters are provided in the closed space.

16. The sensor of any preceding claim, wherein the gas has a low heat transfer coefficient.

17. The sensor of claim 16, wherein the gas is pressurised.

18. A method of fabricating an acceleration sensor, comprising the steps of forming by a photoengraving process a cavity in a semiconductor or insulating substrate and heater and temperature-sensing resistor means extending into the cavity.

19. The method of claim 18, including the step of mounting a further substrate on the first substrate to close the cavity.

20. The method of claim 18, wherein the cavity is formed to extend completely through the substrate and is closed at least at one of its open ends by a further substrate mounted on the first substrate.

21. An acceleration sensor comprising a pair of spaced apart resistor means disposed, in use, in a gas-filled closed space, gas in the space being heated by at least one of the elements, and an acceleration acting on the sensor being detected by monitoring the resistance of at least the other of the resistor means.

Fig. 1

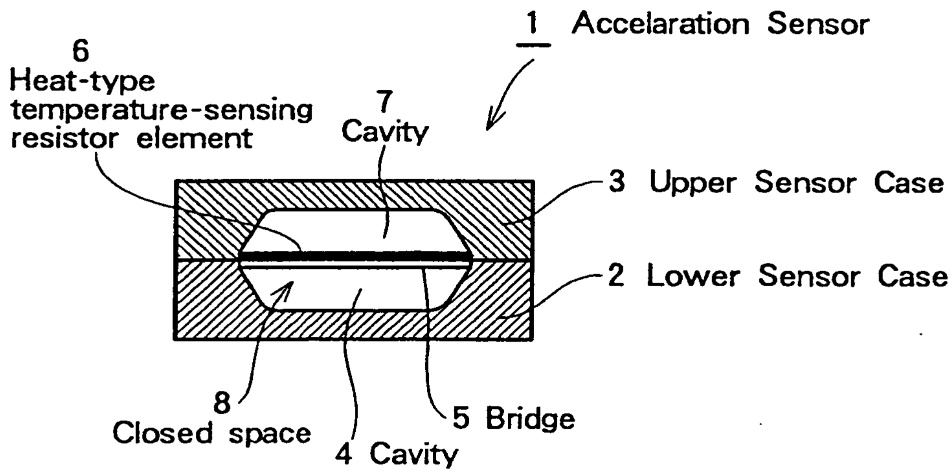

1 Accelaration Sensor
6
Heat-type
temperature-sensing
resistor element
7
Cavity
3 Upper Sensor Case
2 Lower Sensor Case
8
Closed space
4 Cavity
5 Bridge

Fig. 2

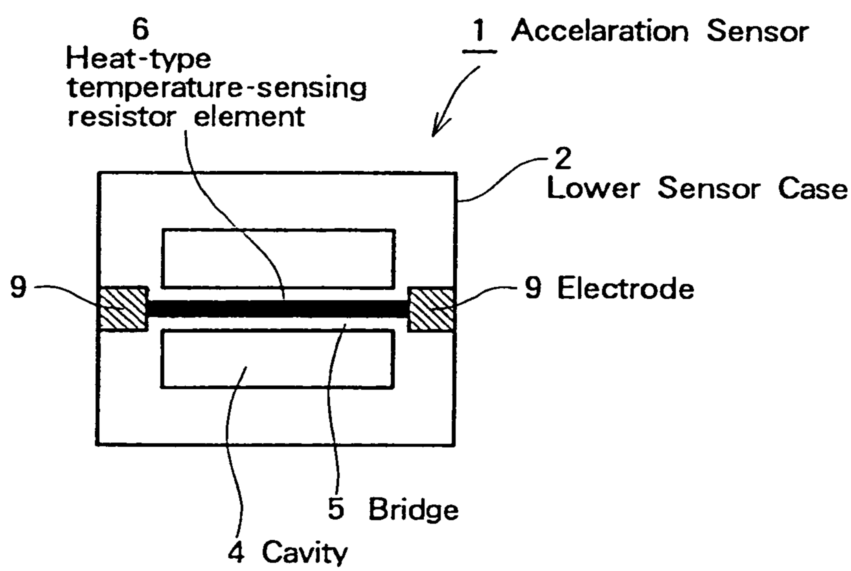

6
Heat-type
temperature-sensing
resistor element
1 Accelaration Sensor
2
Lower Sensor Case
9
9 Electrode
5 Bridge
4 Cavity

Fig. 3

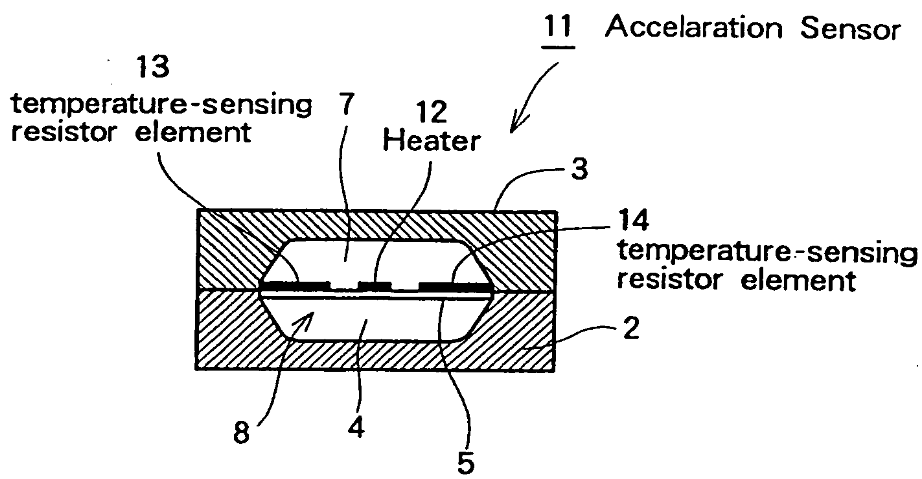

11 Accelaration Sensor
13
temperature-sensing resistor element
7
12
Heater
3
14
temperature-sensing resistor element
2
8
4
5

Fig. 4

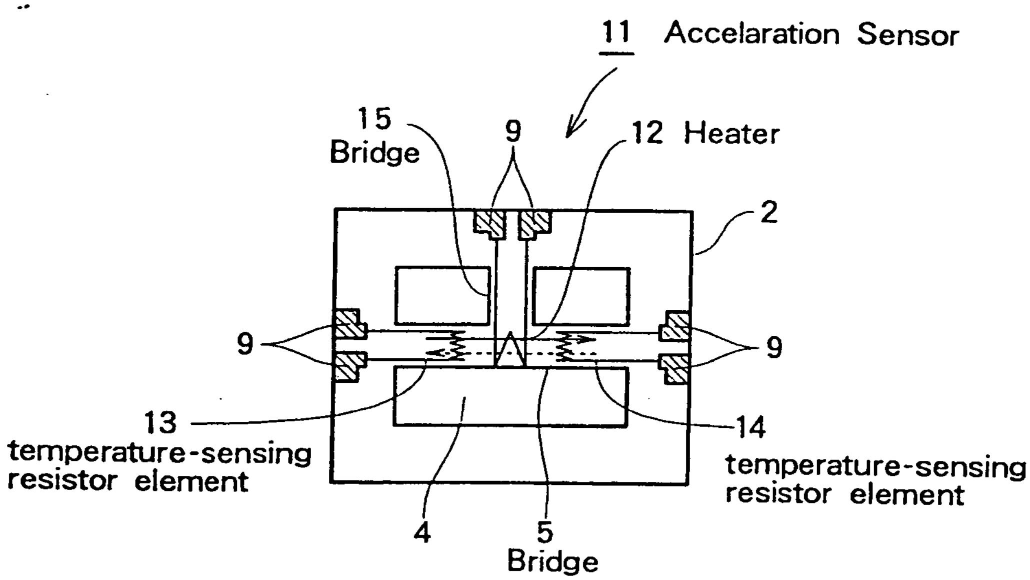

11 Accelaration Sensor
15
Bridge
9
12 Heater
2
9
9
13
temperature-sensing resistor element
14
temperature-sensing resistor element
4
5
Bridge

Fig. 5

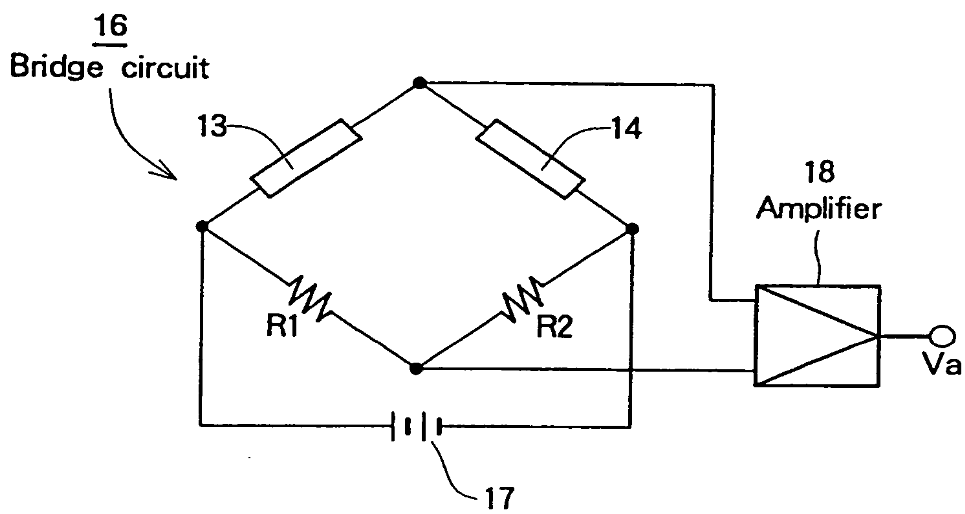

16
Bridge circuit
13
14
18
Amplifier
R1
R2
Va
17

Fig. 6

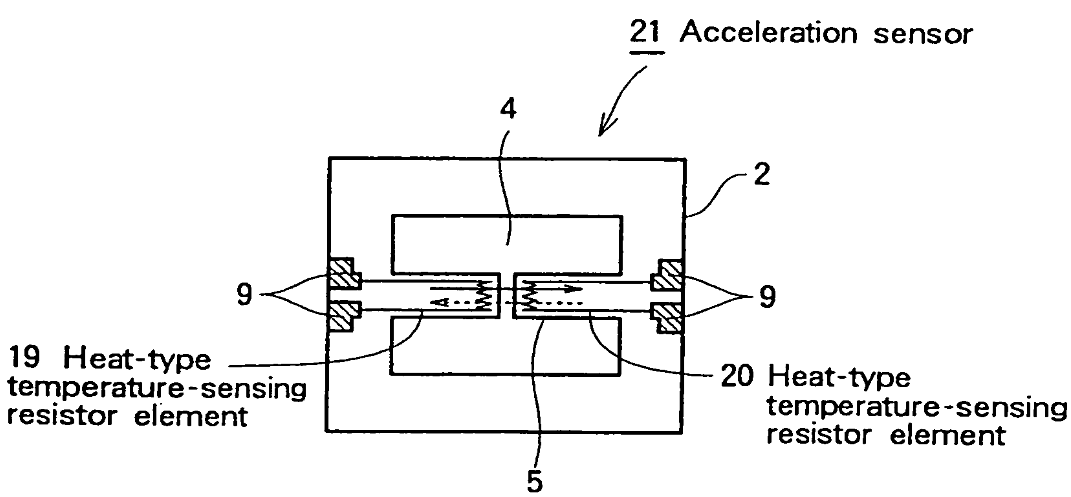

21 Acceleration sensor
4
2
9
9
19 Heat-type temperature-sensing resistor element
20 Heat-type temperature-sensing resistor element
5

Fig. 7

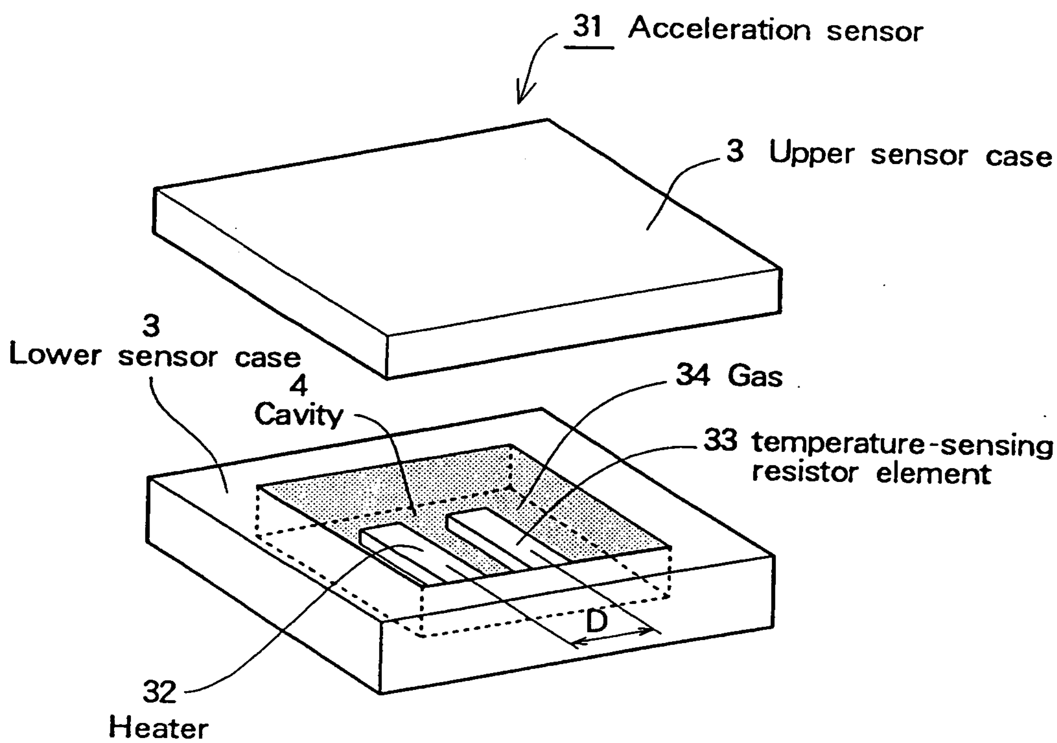

31 Acceleration sensor
3 Upper sensor case
3
Lower sensor case
4
Cavity
34 Gas
33 temperature-sensing resistor element
D
32
Heater

Fig. 8

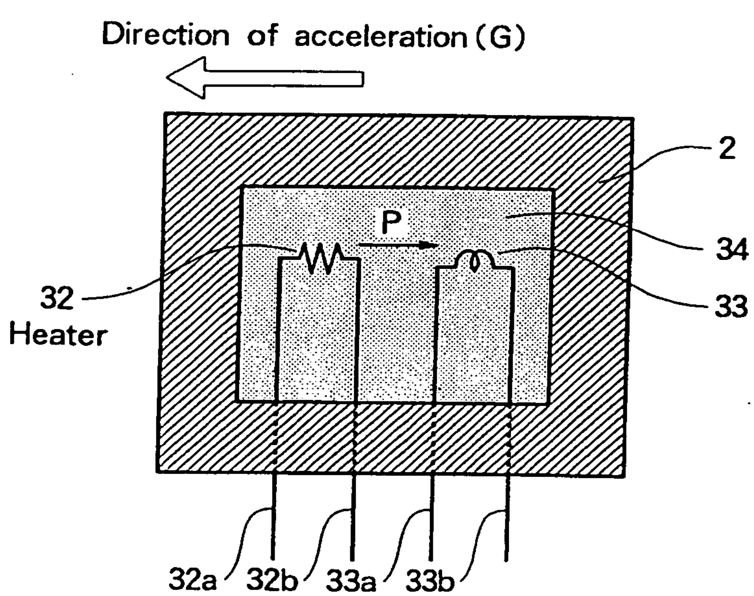

Direction of acceleration (G)
2
P
34
33
32
Heater
32a
32b
33a
33b

Fig. 9

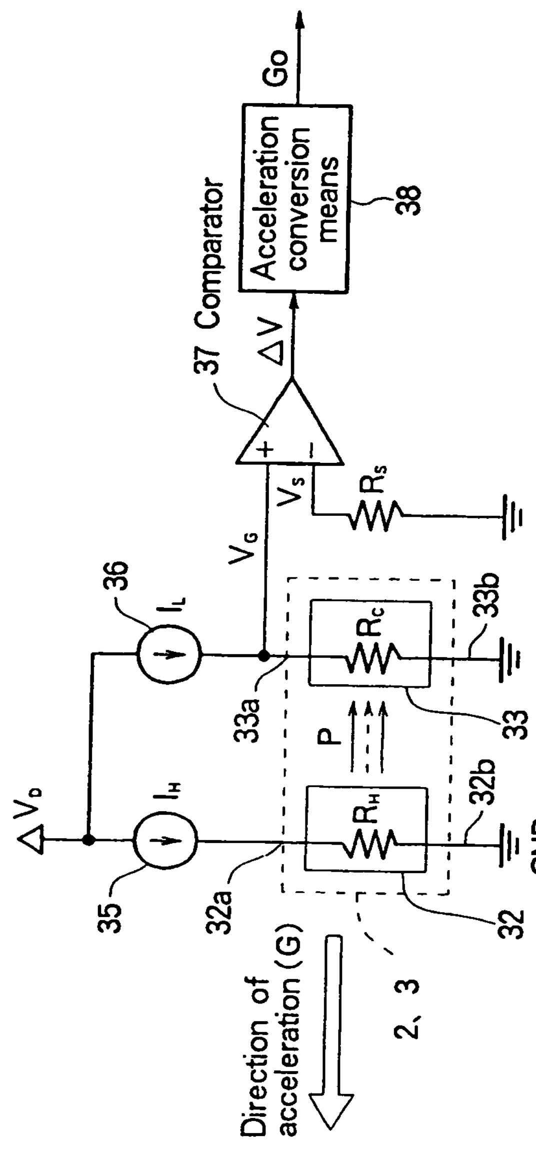

V_D
I_H
I_L
35
36
V_G
V_S
R_S
37 Comparator
ΔV
Acceleration conversion means
38
Go
R_H
R_C
P
32a
33a
32b
33b
32
33
GND
Direction of acceleration (G)
2, 3

Fig.10

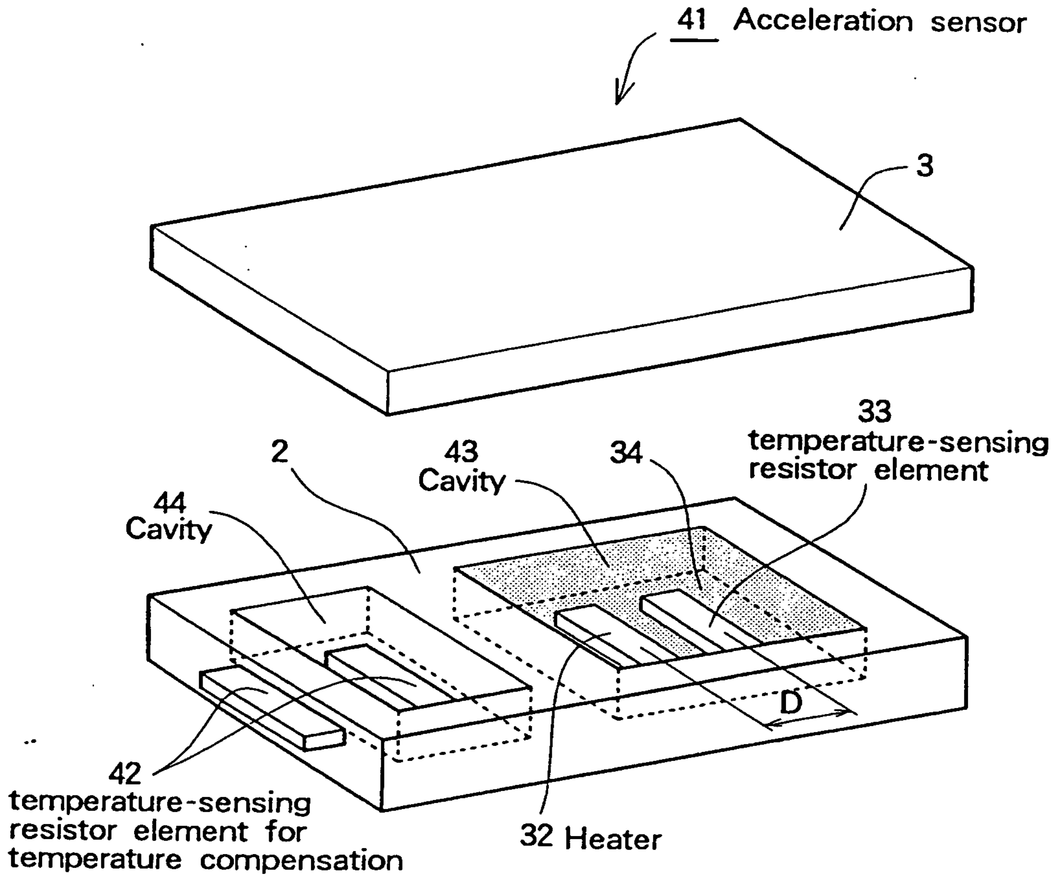

41 Acceleration sensor
3
2
43
Cavity
34
33
temperature-sensing
resistor element
44
Cavity
D
42
temperature-sensing
resistor element for
temperature compensation
32 Heater

Fig.11

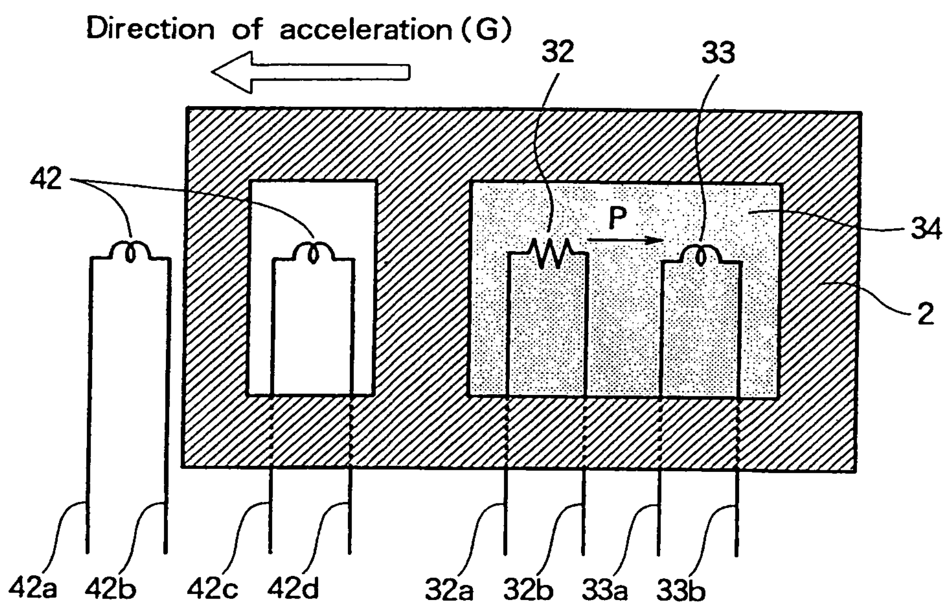

Direction of acceleration (G)
32
33
42
P
34
2
42a
42b
42c
42d
32a
32b
33a
33b

Fig.12

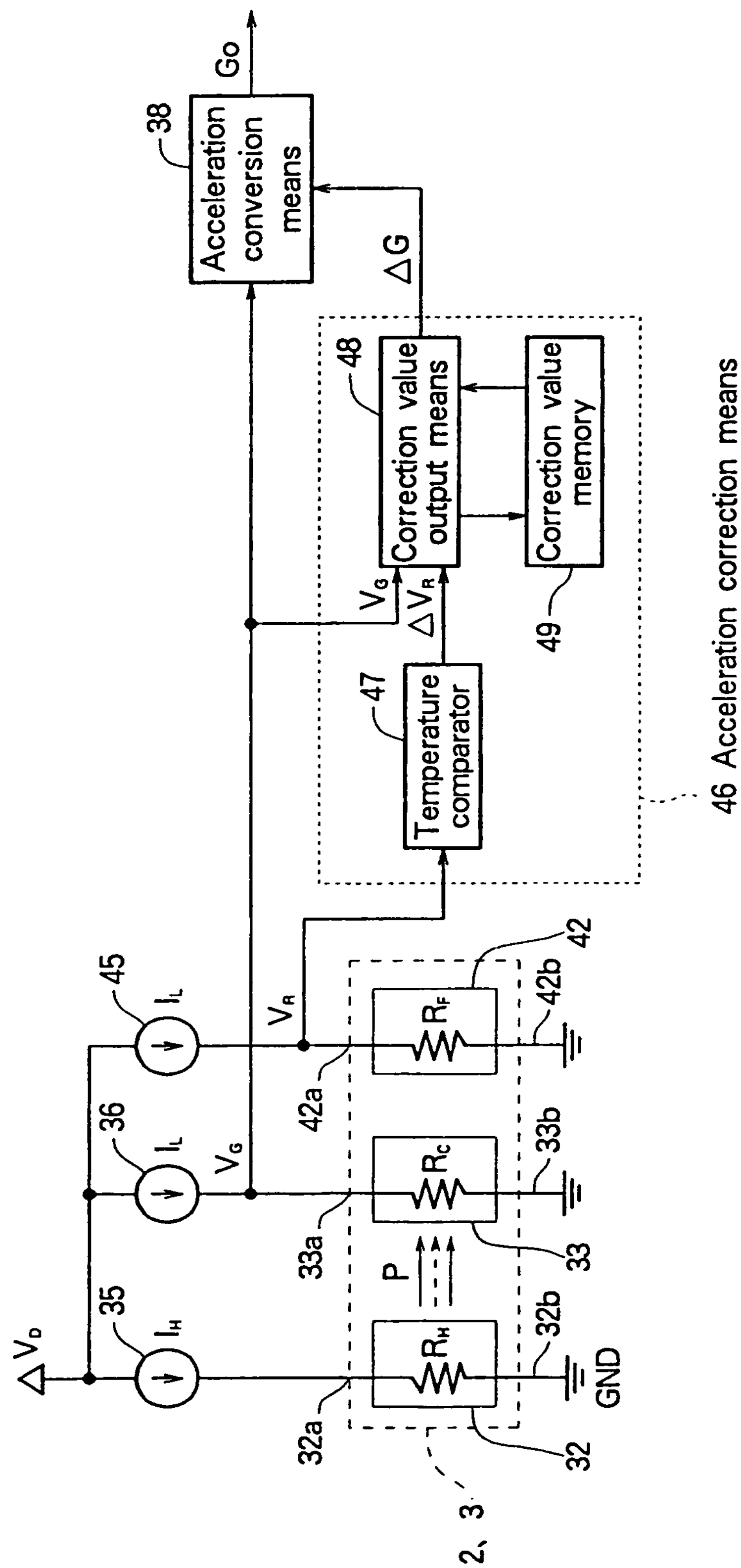

Acceleration conversion means
38
Go
ΔG
Correction value output means
48
Correction value memory
49
Temperature comparator
47
46 Acceleration correction means
V_G
ΔV_R
V_R
V_D
35
I_H
36
I_L
45
I_L
R_H
R_C
R_F
P
32a
32b
32
33a
33b
33
42a
42b
42
GND
2, 3

Fig.13

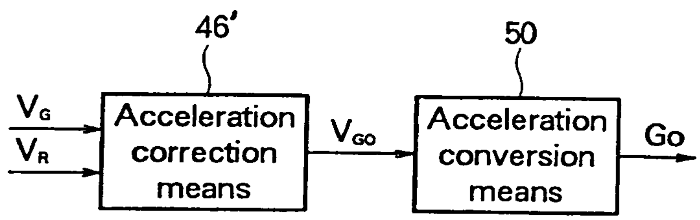

46'
50
V_G
V_R
Acceleration correction means
V_{GO}
Acceleration conversion means
Go

Fig.14

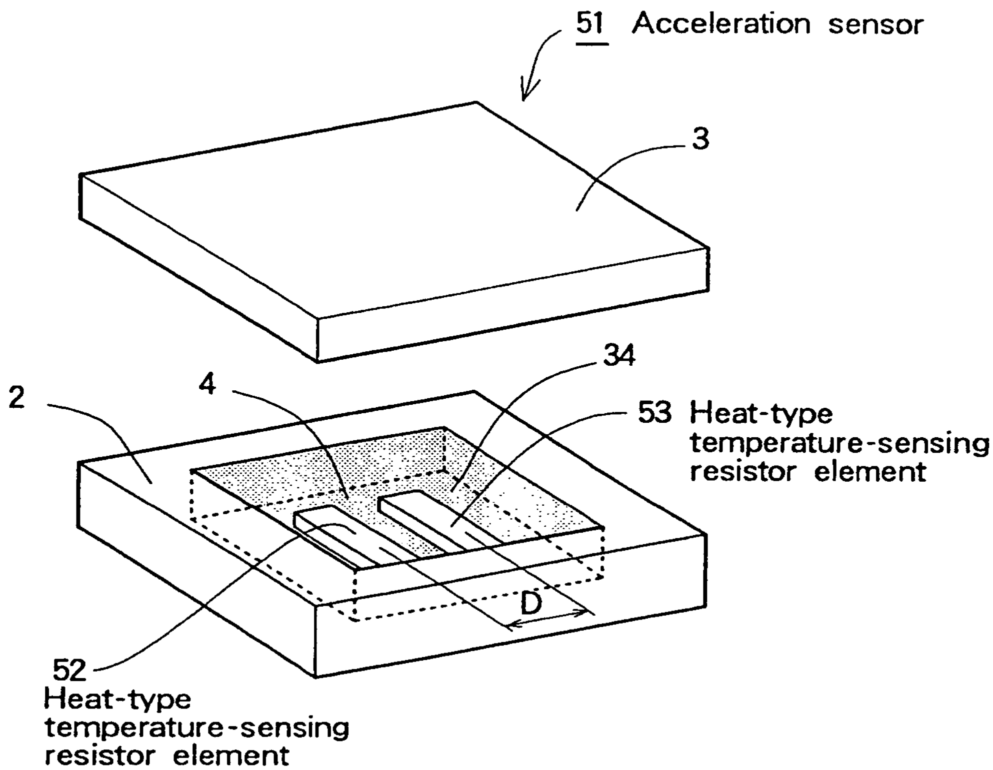

51 Acceleration sensor
3
34
2
4
53 Heat-type temperature-sensing resistor element
D
52 Heat-type temperature-sensing resistor element

Fig.15

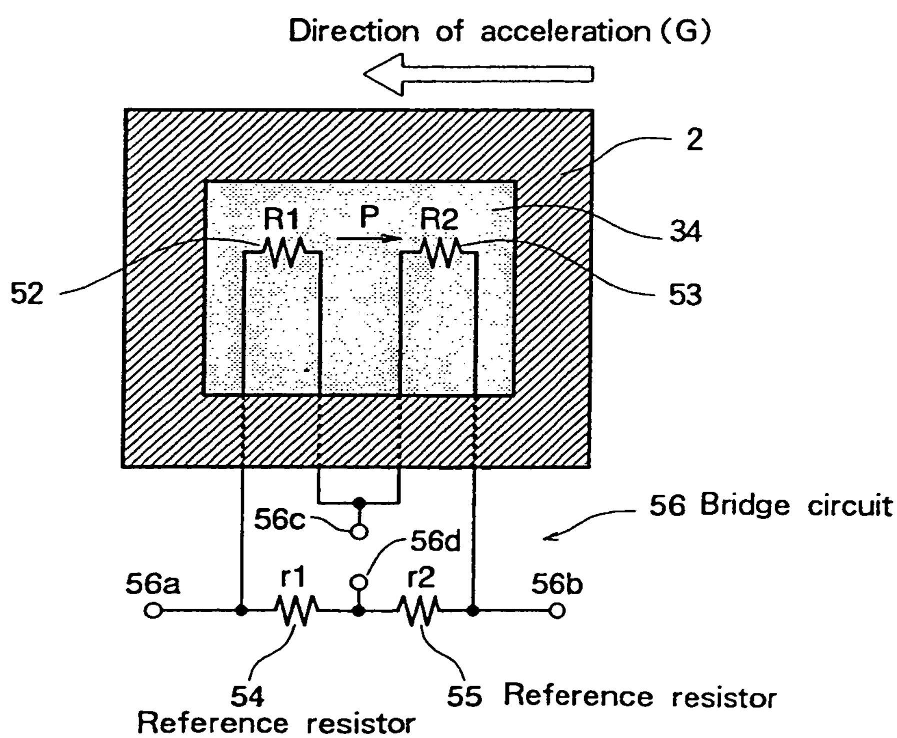

Direction of acceleration (G)
2
R1
P
R2
34
52
53
56 Bridge circuit
56c
56d
56a
r1
r2
56b
54 Reference resistor
55 Reference resistor

Fig.16

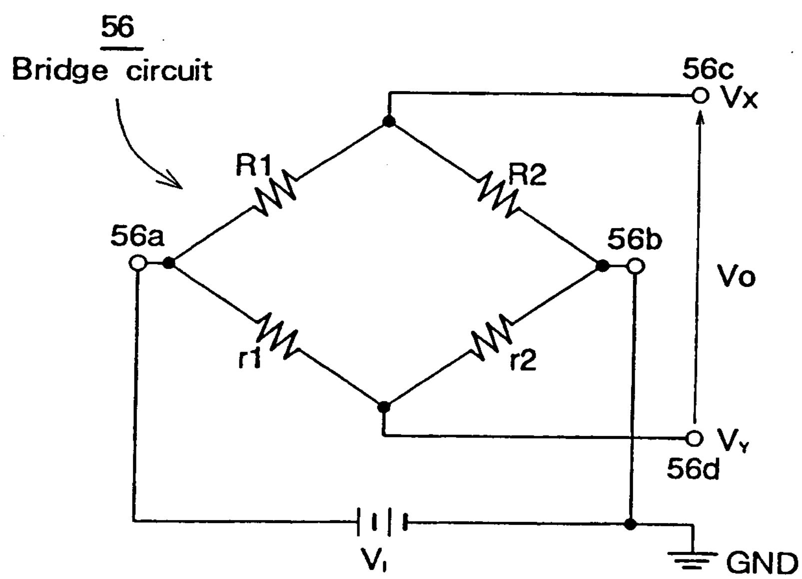


Fig.17

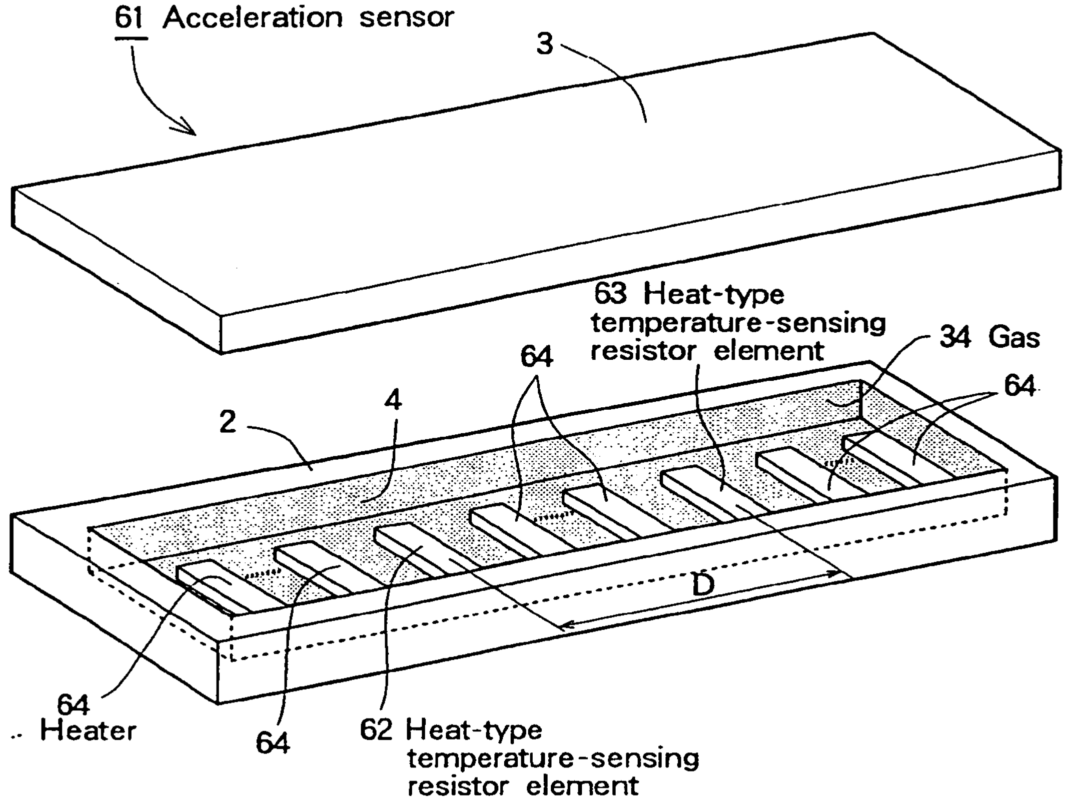

61 Acceleration sensor
3
63 Heat-type temperature-sensing resistor element
34 Gas
64
64
4
2
D
64
Heater
64
62 Heat-type temperature-sensing resistor element

Fig.18

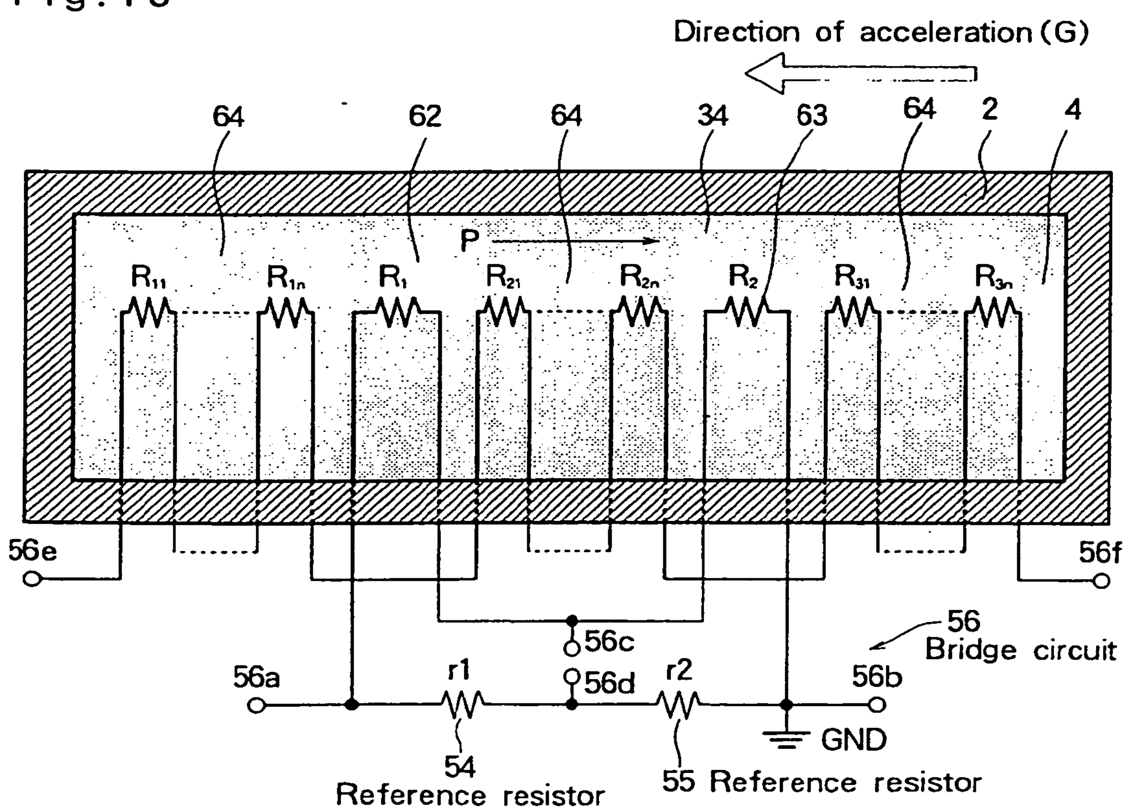

Direction of acceleration (G)
64
62
64
34
63
64
2
4
P
R_{11}
R_{1n}
R_1
R_{21}
R_{2n}
R_2
R_{31}
R_{3n}
56e
56f
56c
56
Bridge circuit
56a
r1
56d
r2
56b
GND
54
Reference resistor
55 Reference resistor

Fig.19

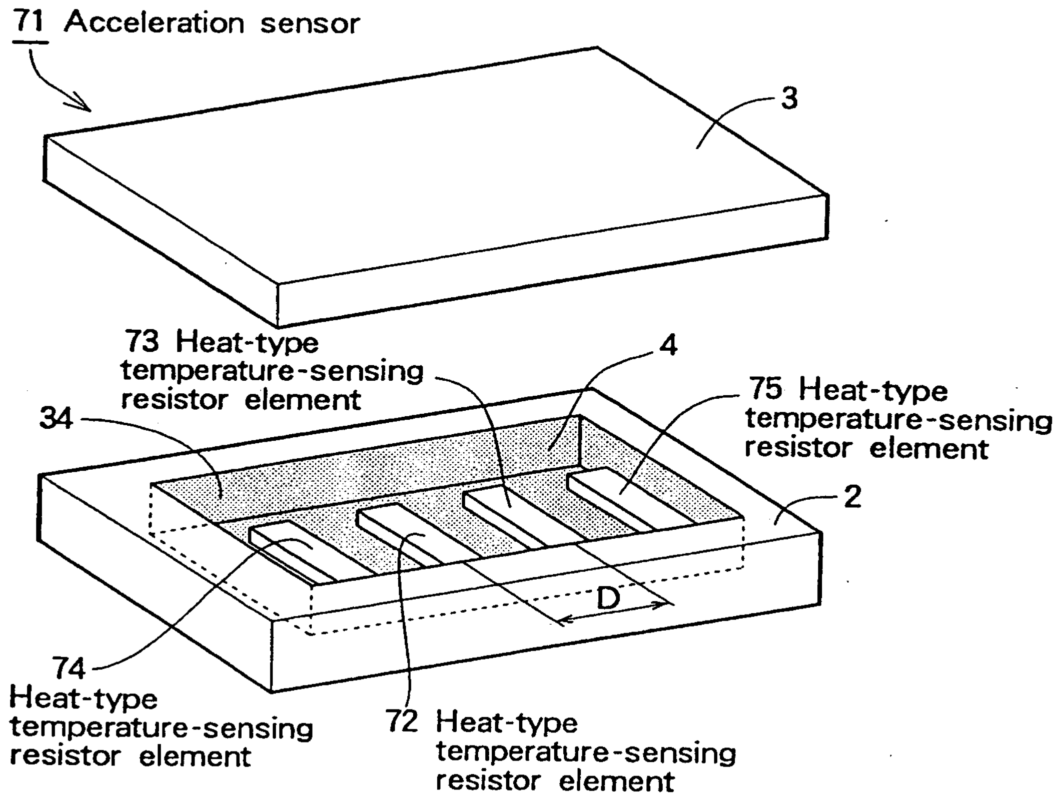

71 Acceleration sensor
3
73 Heat-type temperature-sensing resistor element
4
75 Heat-type temperature-sensing resistor element
34
2
D
74 Heat-type temperature-sensing resistor element
72 Heat-type temperature-sensing resistor element

Fig.20

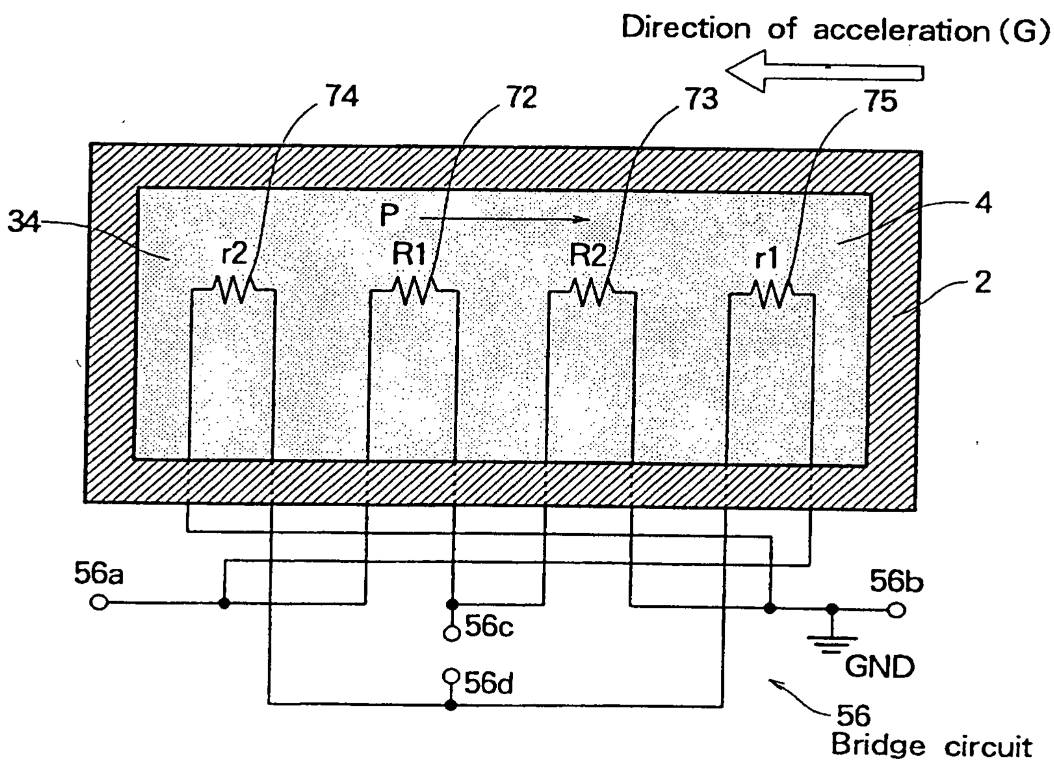

Direction of acceleration (G)
74
72
73
75
34
4
2
P
r2
R1
R2
r1
56a
56b
56c
56d
GND
56 Bridge circuit

Fig.21

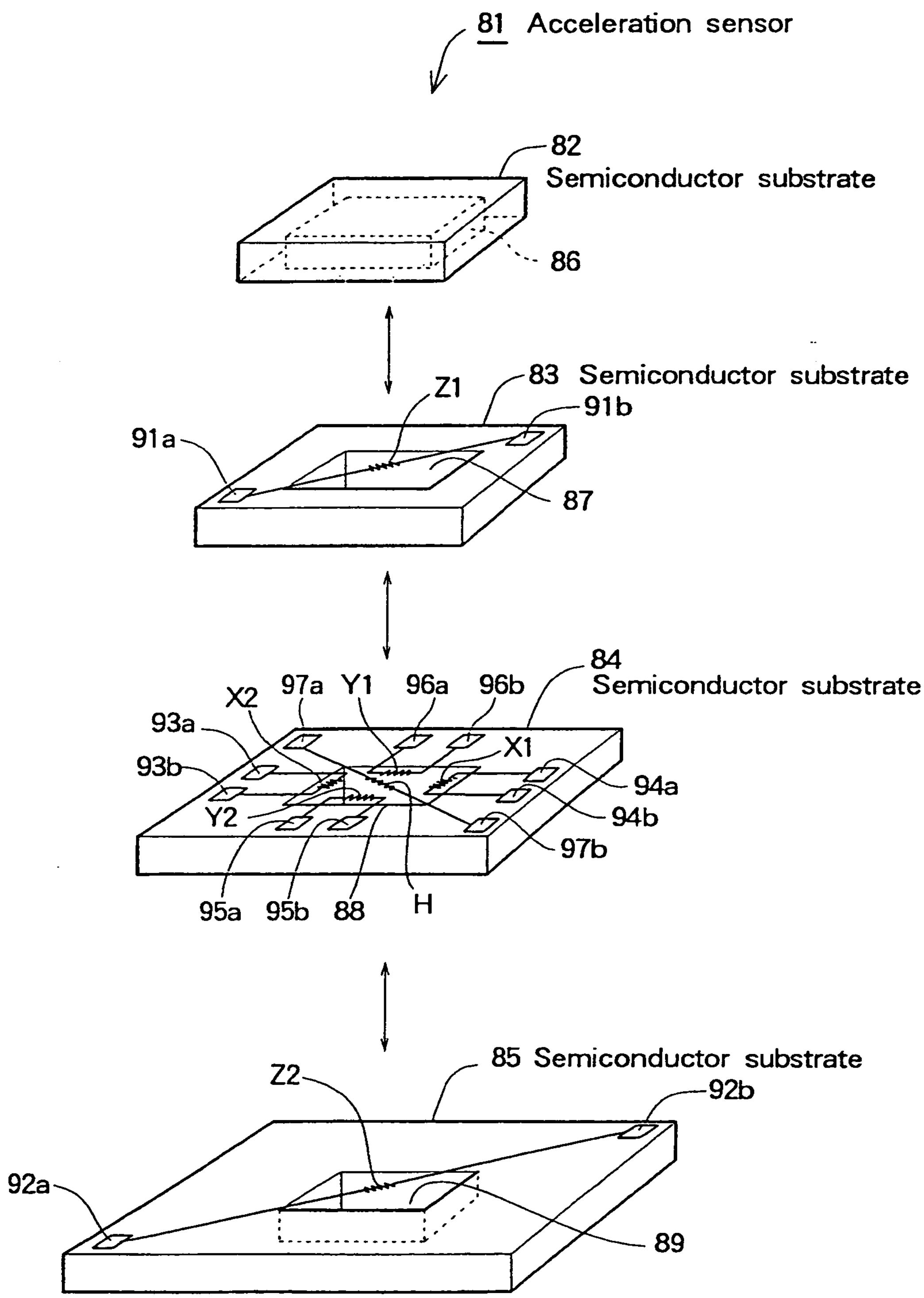

81 Acceleration sensor
82
Semiconductor substrate
86
83 Semiconductor substrate
Z1
91b
91a
87
84
Semiconductor substrate
X2
97a
Y1
96a
96b
93a
X1
93b
94a
Y2
94b
97b
95a
95b
88
H
85 Semiconductor substrate
Z2
92b
92a
89

Fig.22a

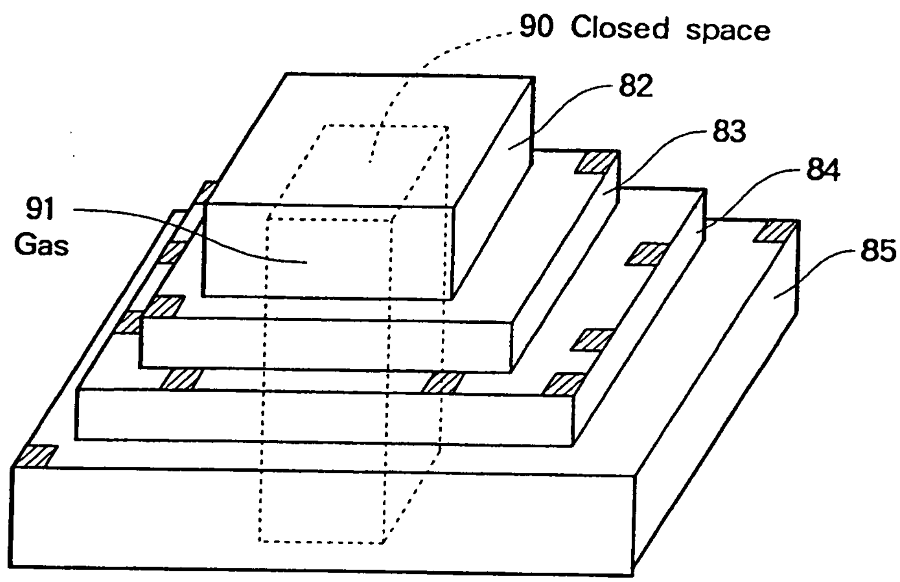


Fig.22b

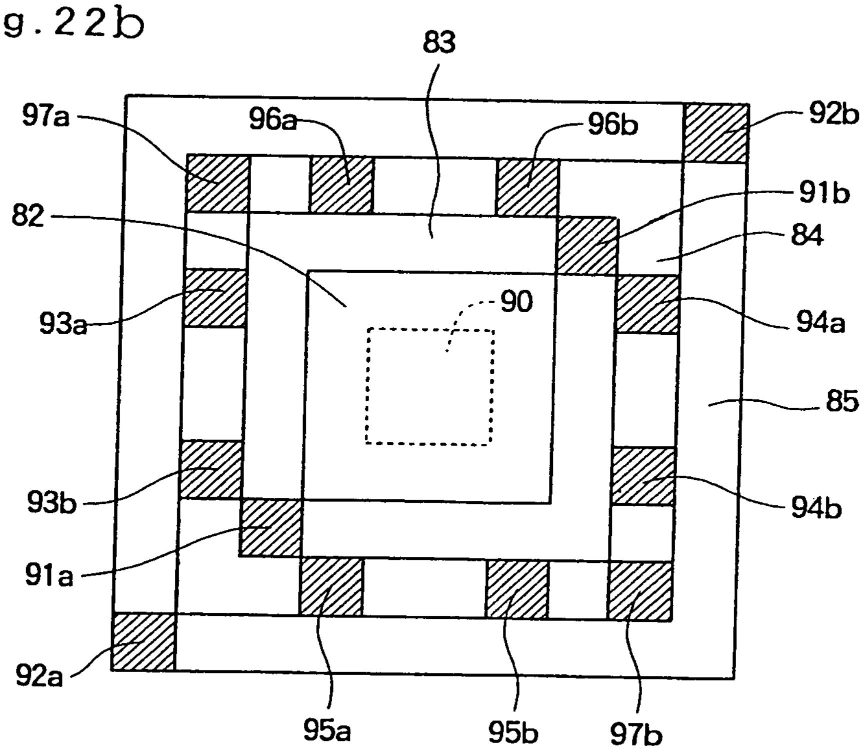


Fig.23

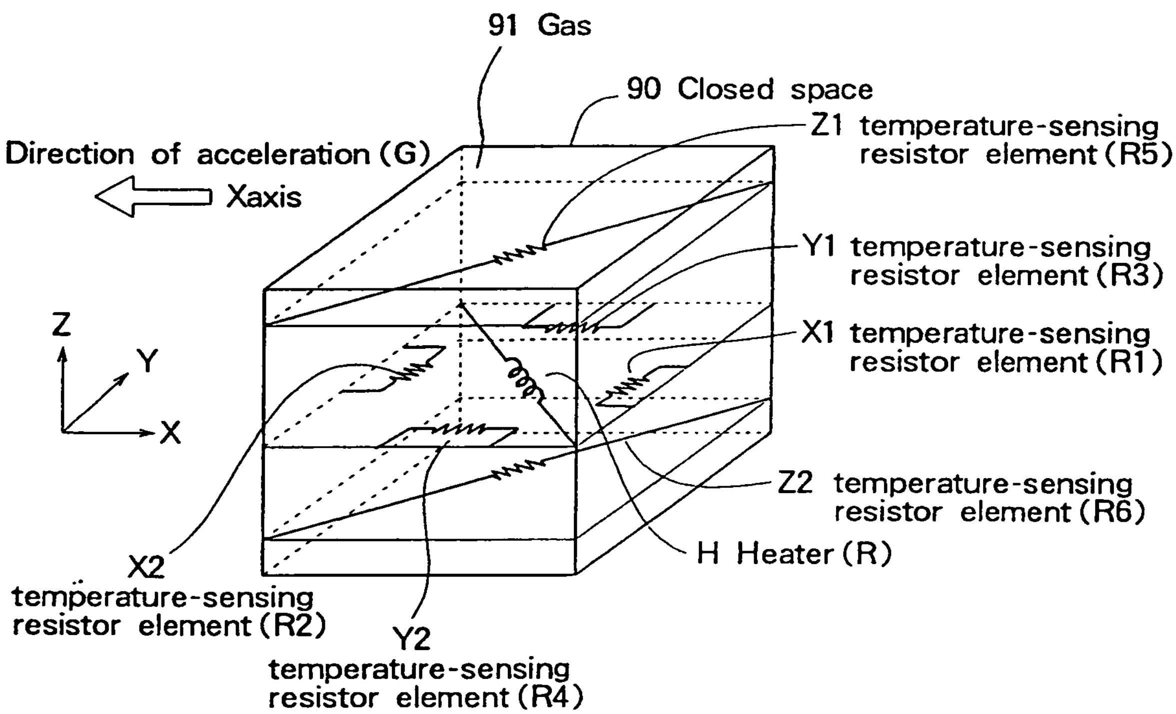

91 Gas
90 Closed space
Direction of acceleration (G)
Xaxis
Z1 temperature-sensing resistor element (R5)
Y1 temperature-sensing resistor element (R3)
X1 temperature-sensing resistor element (R1)
Z
Y
X
Z2 temperature-sensing resistor element (R6)
H Heater (R)
X2 temperature-sensing resistor element (R2)
Y2 temperature-sensing resistor element (R4)

Fig.24

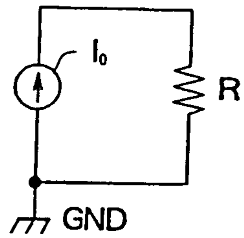


Fig.25

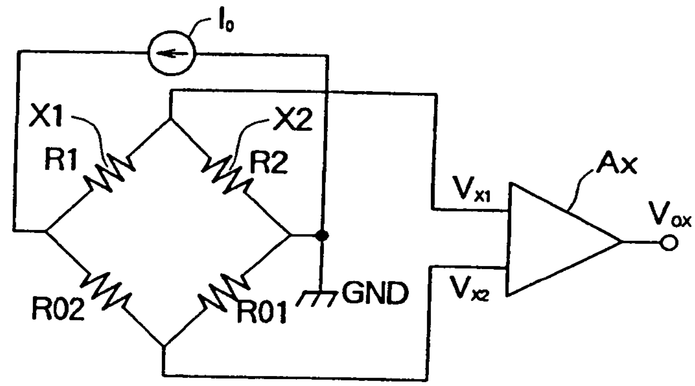


Fig.26

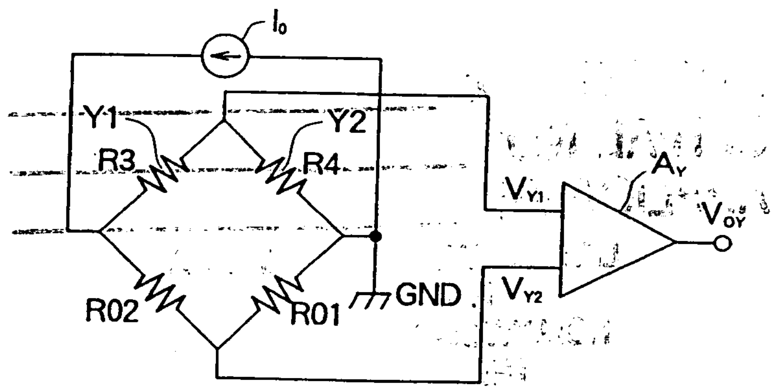
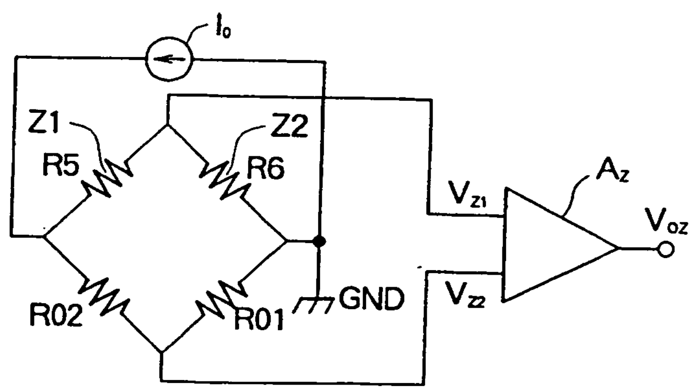


Fig.27



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 30 0345

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	US-A-2 455 394 (H.E.WEBBER) * column 2, line 47 - column 5, line 10; figures 1-4 *	1,2,5,8, 11,16,19	G01P15/12 G01P15/00
A	DE-C-42 43 978 (H.PLÖCHINGER) * column 1, line 43 - column 2, line 34; figures 1-3 *	1,5-9, 11,21	
A D	PATENT ABSTRACTS OF JAPAN vol. 15 no. 426 (P-1269) ,29 October 1991 & JP-A-03 176669 (MURATA MFG CO LTD) * abstract *	1,5,11, 12,14,21	
A	DE-A-41 22 435 (ROBERT BOSCH GMBH) * column 2, line 14 - line 38; figure 1 *	1-3,10, 18-20	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6) G01P

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	28 April 1995	Hansen, P

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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L : document cited for other reasons

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